Risø annual report 1996

Risø National Laboratory, Roskilde

Publication date:
1997

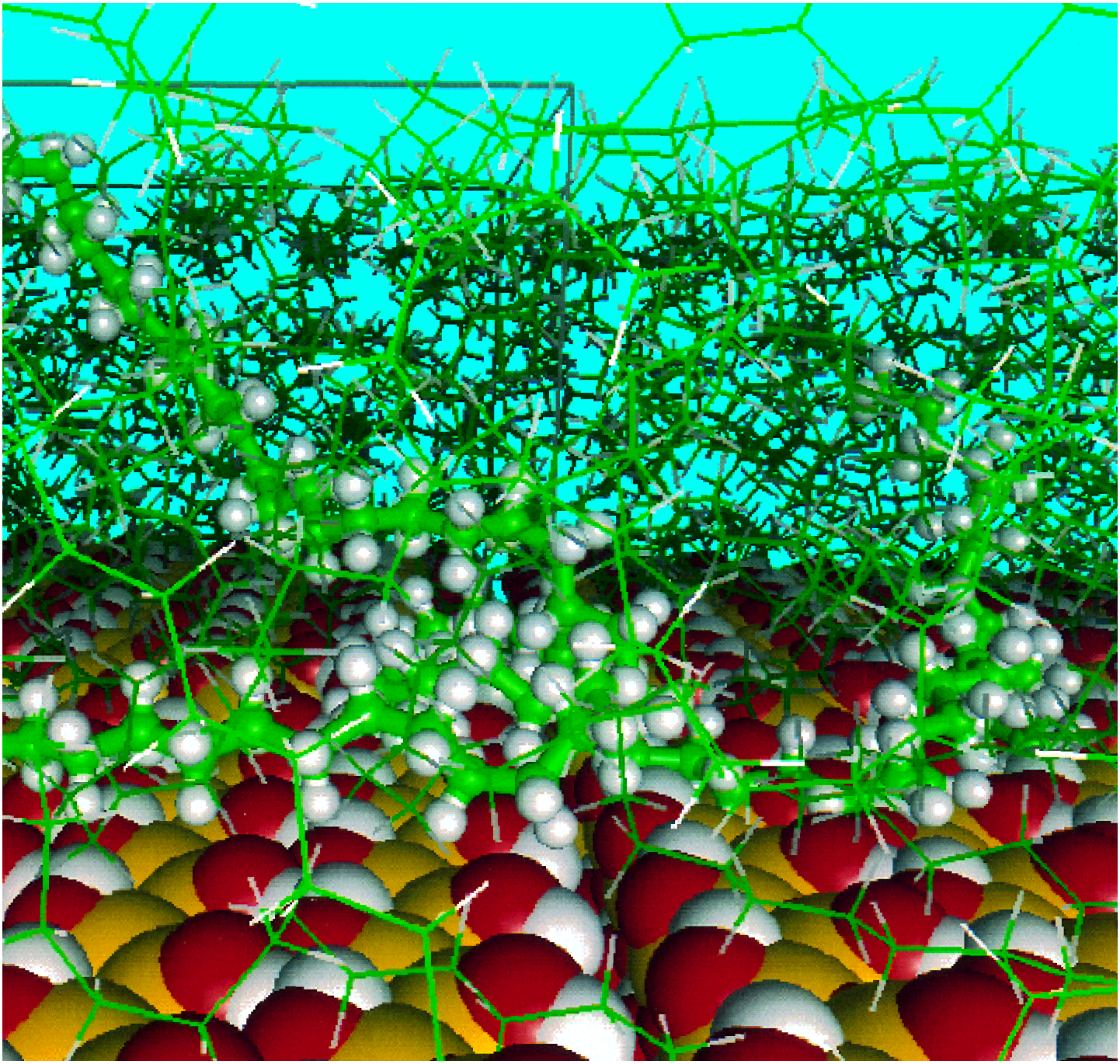
Document Version
Publisher's PDF, also known as Version of record

RISØ

RISØ

ANNUAL REPORT

1996



New strategy

The development in Danish research policy in 1996 created new frameworks for Risø's activities in the years to come.

The Act on Government Research Institutes was accompanied by the new Act on Research Councils and the establishment of the Danish Council for Research Policy. The preceding year's strategy for agricultural research was followed by a partial strategy for environmental and energy research, and with the forthcoming partial strategies for materials science, bio-technological research and the acquisition and operation of costly research equipment, the pieces are starting to fall into place for an overall national research strategy.

Risø welcomes this development and would like to take the opportunity to emphasise the importance of promoting open competition for assignments of a more strategic nature. This will make it possible for the best-qualified research environments, regardless of how they are funded, to solve tasks in collaboration. This yields the best research results and is an expression of a visionary application of public research funds and the will to fulfil large and pressing research tasks.

In July 1996, Risø's governing body adopted a new strategy. This was prepared in the light of the preparations of the national research strategy, and adapted to the trends in the international research programmes, including in particular the programmes offered by the EU.

The strategy includes setting new overall objectives for Risø's research which are also included as a mission statement in Risø's new articles, adopted to comply with the Act on Government Research Institutes.

The research falls within the areas where Risø already has or can attain international impact and is independently positioned in the Danish world of science. Its purpose is to provide the Danish society with new technological development opportunities, and it is directed towards areas of application where it can strengthen the competitive edge of Danish industry and reduce the adverse impact on the environment of industry, energy and agriculture.

The strategy is also an expression of Risø's will to play a constructive role in the world of science, to focus on the needs of society for research and development, and to collaborate with the rest of the world of science and with industry. It distinguishes Risø as a national research centre – a national laboratory – which, as part of its own research and by virtue of its interdisciplinary nature and its infrastructure, takes on assignments for various ministries, government authorities and private companies.

In the autumn of 1996 the Ministry of Research and Information Technology and Risø implemented the second part of a sponsor and user survey as stipulated in the management performance contract with the Ministry. The survey was undertaken by Gallup and showed continuing satisfaction with the activities among Risø's Danish and international sponsors and users.

The survey preceded the international evaluation of Risø, incorporated as an important element of the fulfilment of the management performance contract that runs until the end of 1997. The actual evaluation was carried out in January 1997 with a highly satisfactory result. The evaluation contains a list of recommendations – including a proposal for closer links with industry – which Risø's governing body and management will use as a starting point for Risø's work in the coming year.

Risø's finances in 1996 were characterised by a smaller increase in income than budgeted, mainly as a result of a reduction in demand for irradiated silicon and lower subsidies for wind power research than anticipated. However, Risø continued its investment programme with the setting up of the special greenhouse facility, RERAF, construction of new buildings for the UNEP Collaborating Centre for Energy and the Environment, establishment of a new biological waste water facility and the purchase and expansion of the blade testing centre at Sparkær. These investments were partly financed by drawing on the reserves.

As the following detailed report on activities shows, 1996 was a busy year with many worthwhile results, the most immediately striking of which are particularly highlighted in the text. Included are reports of significant discoveries in the development of new optical measuring techniques and new types of optical information storage, design of new materials, development of a new methods for resistance to the plant disease mildew, and of the transfer of new technology to Danish wind turbine production.

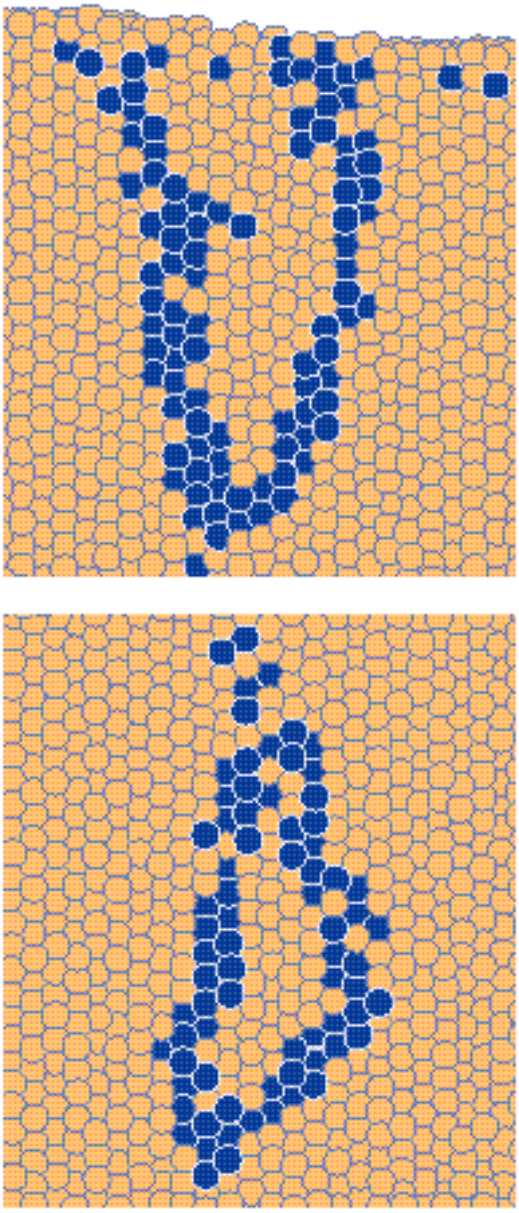
Ulrik V. Lassen
Chairman of the Governing Body

Hans Bjerrum Møller
Managing Director

Industrial materials

Development and characterisation of materials and materials technologies for the purpose of effective and safe application in industrial products, particularly energy technology systems.

Snapshots from simulation showing dislocation annihilation. Surface nucleated cross slip of one of the screw dislocations initiates the annihilation (top) which then proceeds downwards via a dislocation loop.



Materials models and materials structures

Determination of the mechanical behaviour and structural development of materials during deformation. Formulation of mechanical and micromechanical models and models at the atomic level. This lays the groundwork to enable materials-technological limitations to be shifted.

Materials research without limits

The Engineering Science Centre at Risø, supported by the Danish Technical Research Council (STVF), has as one of its objectivesstrengthening of the link between the materials-science dominated activities in the Materials Research Department and the related research areas of condensed matter physics and materials mechanics. The current situation of this type of interdisciplinary research in Denmark and future possibilities were discussed at a meeting in October1996 organised by the Engineering Science Centre. In this section projects are described that exemplify the interdisciplinary research within the framework of the Centre.

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Dislocations are the key to understanding the behaviour of metals

Plastic deformation of metals takes place by the motion of dislocations. Dislocations are defects in the otherwise regular arrangement of metal atoms in the crystal lattice. Plastic deformation involves complex interactions of numerous dislocations. However, certain basic processes in dislocation dynamics involve only one or two dislocations. Such processes may now be investigated by means of atomic-scale modelling. In a collaborative venture between the Technical University of Denmark (DTU) and the Engineering Science Centre, the elimination of two dislocations by so-called cross-slip was observed for the first time in a numerical simulation on the atomic scale. Such modelling connects the world of materials science on the mesoscale and microscale with the atomic-scale world of materials physics.

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Micromechanisms of metal fatigue

Dislocation processes at the atomic level are the ultimate cause of metal fatigue, which involves the nucleation, accumulation and propagation of surface cracks. Crack nucleation occurs at the microscopial level either through wavy slip with high cross-slip frequency, or through planar slip with low cross-slip frequency. At Risø, mechanisms of crack nucleation have been mapped and modelled for the copper model system, which deforms by wavy slip. Ongoing studies of copper-zinc aim to shed light on the mechanisms of metal fatigue in planar slip materials. The work covers mesoscale damage-mechanical simulation of crack accumulation and propagation by numerical Monte Carlo modelling. The results of the model studies are exploited in work on more complex industrial materials. In duplex steel, some crystal grains deform by wavy slip and others by planar slip. In collaboration with Université de Lille and Ecole des Mines de Saint-Etienne, France, Risø is investigating the effects of grain morphology and chemical composition on the internal stresses and fatigue of duplex steels.

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Crack propagation in ceramics

Most engineering materials are designed to resist fracture. However, it is difficult to obtain accurate measurements of fracture toughness with brittle materials. Risø has, therefore, developed a special test fixture for fracture mechanics testing inside an environmental scanning electron microscope. The fixture makes it possible to create stable crack propagation in the materials being studied. Crack propagation is detected either by direct observation of the crack tip under strong magnification or by acoustic emission. Because of the way the test fixture operates, cracks can be arrested after small extensions, even in brittle materials such as ceramics. This enables in-situ observations, which give a direct relationship between the toughening mechanisms operating during crack propagation and their effect on fracture toughness. This information is useful for the modelling of toughening mechanisms.

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Local structures and properties

Determination of relationships between microstructure and local crystallographic orientations for the purpose of understanding and controlling mechanical characteristics and recrystallisation.

More knowledge of metal-rolling

It is well known that the mechanical properties of metals and alloys are typically anisotropic, i.e. they differ in different directions in the metal. This can be of great importance to the

strength of the material, particularly when, for example, it is desirable to use sheet materials that are as thin as possible because of weight and material consumption considerations. Risø has set up a new model that explains some of these matters, and the model has been tested for a number of materials parameters in cold-rolled aluminium. The model results have alsobeencomparedwithmeasurements in cold-rolled aluminium sheets, and a strong correlation has been found between theory and practice. This research is part of a centre collaboration between the Technical University of Denmark and the AAU, financed by the MUP programme.

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From polycrystals to single crystals and back again

By far the majority of industrial materials are polycrystalline, i.e. they are composed of small grains or crystals, normally of between 1/100 mm and 1/2 mm. These grains are linked in grain boundaries that have properties which differ from the grains themselves. To understand the behaviour of grains under the influence of existing grain boundaries better, structural development during deformation has been studied in a number of single crystals with different crystallographic orientations, which develop different deformation microstructures. Microstructural parameters have been established using automatic electron microscopy techniques.The information shows to some extent how the crystals are deformed, and it can also be used to calculate the strength of the crystals. By studying crystals of different crystallographic orientations and comparing them with grains of corresponding orientation that are present in a polycrystal clear correlation has been found. Among other things, this now makes it possible to correlate what were formerly regarded as inexplicable irregularities in the polycrystalline structure with the crystallographic orientation of the individual grain. These orientations can be measured and the structural change and strength of the polycrystals during deformation can, therefore, to some extent be predicted, based on the behaviour of the single crystals.

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Irradiation damage, defects and fusion materials

The production, reciprocal action and accumulation of defects, and the influence of these processes on properties of materials for use in a fusion reactor.

Scanning Electron Micrograph showing the fracture surface of a sample of a molybdenum-5%rhenium alloy irradiated with neutrons in DR3 and tensile tested. The micrograph reveals that the material did not deform plastically but has failed by brittle fracture.

Irradiation damage to constructional materials of fusion reactors

The construction materials adjoining the plasma in fusion reactors are subjected to heavy bombardment by neutrons of extremely high energy. This may cause an appreciable amount of damage in the materials, a phenomenon that may be decisive for the commercial use of fusion reactors for electricity generation. To study the effect, Risø has carried out irradiation of copper in collaboration with the research centre at Jülich in Germany (IFF). The resultant microstructure has been investigated by transmission electron microscopy (TEM) and positron annihilation spectroscopy (PAS). The studies have shown that the defects accumulate in line with increasing projectile energy, which corroborates theoretical predictions. This research is part of the EU fusion research programme and the Risø/Euratom association.

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Design of light-weight components

Numeric and experimental methods and techniques for the modelling and characterisation of advanced construction materials and components.

Fatigue in forging tools

High-strength materials are used for tools in metal-forming processes such as cold-forging and extrusion. The materials in the forming tools are subjected to repeated loading under high stresses, which may result in dimensional changes and sudden fractures. Risø has developed a number of models to describe this process, based on extensive mechanical testing of high-performance tooling materials. The models can predict the useful life of commercially used tools and the study has increased actual tool life by up to a factor of ten. The project has been carried out under the Danish MUP1 and MUP2 programmes with support from industry. Work is now continuing supported solely by Danish industry.

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Fatigue in polymer composite materials

Glass or carbon-fibre polymer composites are widely used, for example, in wind turbine airfoils and aircraft structures, where they are subjected to fatigue loads. These loads may be the limiting design factor in a number of applications, and reliable fatigue diagrams are essential for designing components. Fatigue diagrams to high cyclic loads (more than 10 million cycles) are very expensive to establish by traditional methods. By studying the stiffness degradation during fatigue experiments, Risø has demonstrated that stiffness fatigue curves can be set up based on a more restricted number of experiments.

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Advanced composite materials

Determination of the microstructure of composite materials and fibres as well as mechanical and physical properties.

Metallic composites make lighter automotive components

Aluminium alloys reinforced with ceramic particles, so-called metal matrix composites (Al-MMCs), have become cheaper and, therefore, increasingly available. Environmental concerns such as lower weight, with consequently lower fuel consumption, as well as recycling of materials from used automotive components, have

Cutting of hybrid yarn fabric for manufacturing of fibre reinforced thermoplastic composites. Pre-heating and consolidation of a stack of the hybrid yarn fabric to a composite material is done on a new press line.

contributed to increased interest in these materials. In private cars, Al-MMCs may be substituted to advantage in a range of components which have traditionally been manufactured from steel or cast iron. At Risø, the properties and potential of these materials are being investigated, based on commercially available Al-MMCs. The industrial application of Al-MMCs is being studied in a BRITE-EURAM programme incorporating the forging of a number of selected automotive components such as brake drums and brake disks. Braking components have been tested under simulated operating conditions, where they prove to have better properties than normal cast iron brakes. The material has good wear-resistance properties and better heat conductivity, ensuring a lower, more uniform temperature during braking. The weight of the braking component has been reduced from approximately six kg to approximately three kg. The experience gained will be used in the manufacture and testing of selected automotive components, initially in the form of niche products. In the longer term, this technology is expected to expand to trains and space travel, for example.

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Polymeric composites in advanced wind turbine rotor blades

As rotor blades for wind turbines increase in size, design becomes more critical. At the same time, the blades are becoming more slender, making them more susceptible to vibrations under variable wind loads. Materials for wind turbine rotor blades are composites, based on various principles. With support from the EFP, the Danish Energy Research Programme, Risø is studying the traditional glass fibre/polyester materials with new fibre configurations. Carbon fibre/epoxy materials and wood/epoxy composites are new in the context of blades, and they are currently under investigation. Hybrid composites of glass fibre and carbon fibre with polyester matrices are also being considered for blades, and are included in the studies. The main emphasis in the investigations is on fatigue load under conditions corresponding to the mechanical loads to which wind turbine rotor blades are subjected. One of the objectives is to set up fatigue curves that may also be a part of the construction considerations as early as the design phase.

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Natural fibres for construction materials

Natural fibres based on wood and other plants can be exploited for structural and load-bearing purposes. Plant fibres such as flax and hemp are cellulose based and have mechanical properties comparable to synthetic fibres, such as glass and polyethylene. They are, therefore, potential reinforcing fibres for composite materials based on polymers as matrices. Risø is investigating how to manufacture and exploit fibres from natural materials. A key point is that the transformation of natural materials into cellulose fibres is a process requiring energy. A wet oxidation technique developed by Risø has now opened up the possibility of reducing energy consumption and at the same time, exploiting the by-products from the manufacturing process. The project is part of a collaborative venture between the Royal Veterinary and Agricultural College (KVL) and the Technical University of Denmark (DTU).

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Manufacturing technologies for advanced materials

Development of process and manufacturing technologies for polymer-based composite materials as well as characterisation of test samples.

New manufacturing technologies for fibre-reinforced thermoplastics

In an ongoing three-year project under the Danish Materials Technology Programme (MUP), a new type of hybrid yarn of glass fibres and thermoplastic polyester fibres is under development. The development work is being carried out in collaboration with A/S Kaj Neckelmann, Komposit Procesteknik ApS, and LM Glasfiber A/S. The concept for the new material is faster processing, a much cleaner working environment and easier recycling. A new, fully automated and instrumented press facility, incorporating material heating and handling equipment, is used to develop the pressing process, which is suitable for fast production of medium-sized components in a large series, e.g. car body panels. Vacuum consolidation technology is also under development. Vacuum consolidation is suitable for the production of very large components, e.g. wind turbine blades and transportation containers. The work is also of interest to the textile industry for production of semi-raw materials such as textured yarn, woven fabrics, etc.

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Powder technological materials

Development of powder-based materials and process technologies for the purpose of improving properties as well as testing and characterising the manufactured materials.

Materials of stainless steel powders

Powder metals have many advantages over conventional forging and casting and the technique has already been developed for a wide range of metals including steels. The technique is used by many Danish export businesses, which manufacture or use stainless steel parts in a range of applications, for example pumps in corrosive fluids. One problem with these processes is that unless very high – and expensive – process temperatures are applied, the sintering of stainless steel powders causes some porosity in the finished part, impairing corrosion resistance in particular. The lowering of these

temperatures can be achieved by adding agents that cause liquid phase sintering. In collaboration with Danish companies, Risø is involved in an MUP programme to develop and characterise these process techniques so that it will be possible to establish suitable sintering conditions for stainless steel powders. This knowledge is expected to be applicable to other systems. The objective is to bring down the cost of production of compact stainless steel parts. In collaboration with the Danish Technological Institute, Risø organised a Nordic conference on powder metallurgy, which took place in Copenhagen in November 1996.

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New electroceramic materials

For the development of new technologies in the fields of energy, microelectronics, aerospace, etc., there is growing demand for ceramic materials possessing a combination of properties which cannot be obtained with classical ceramic materials. There is, therefore, considerable interest in the so-called functionally gradient materials, FGMs, where properties can be adapted by varying component construction and/or the microstructure of components. Risø's research in this area is focused on electroceramic materials, and the work is carried out under MUP in close collaboration with Ferroperm Components, a division of AMP, Denmark, PBI Dansensor A/S, Haldor Topsøe A/S and the University of Copenhagen. Efforts are concentrated on materials research and development of new technologies for production of microelectronic components, electrolytes for ceramic reactors and ceramic gas sensors. An open seminar was held at Risø in the autumn of 1996 on ceramic sensors. The research is carried out under the auspices of the MUP2.2 framework.

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Fuel cells

Development of fuel cells based on ceramic materials for direct conversion of hydrogen, coal gas and natural gas to electricity.

New and more competitive fuel cells

Ceramic fuel cells (SOFC) can transform fuels such as coal gas and hydrogen directly into electric energy through an electrochemical process that is far more effective and environmentally friendly than traditional combustion. The individual ceramic fuel cells each deliver a voltage of approximately 1 volt, and several cells are assembled into stacks to achieve higher voltage and power. All components for an additional ½ kW solid oxide fuel cell stack have been manufactured in collaboration with Haldor Topsøe A/S and Innovision R&D A/S. The stack is to be instrumented with thermocouples, oxygen probes and potential probes, aiming at experimental verification of computer models developed for the description of stack behaviour. Based on an economic analysis undertaken by Haldor Topsøe, ELSAM and Risø, methods and design modifications have been suggested which may reduce SOFC stack manufacturing costs to levels competitive with those of other electric power generation technologies. This research and development is supported by the Danish Energy Agency and ELSAM and is carried out in collaboration by ELSAM, Haldor Topsøe A/S, Innovision A/S and institutes at Odense University and the Technical University of Denmark. The project is led by Risø. To supplement the Danish programme, a JOULE III (EU) project was initiated at the beginning of the year. The project focuses on extending the lifetime of SOFC components and is being implemented with Risø coordinating the collaboration of a number of leading European companies in the SOFC technology area – Siemens, Daimler-Benz/Dornier, Rolls Royce, Statoil A/S, KFA-Jülich, ECN (The Netherlands), Imperial College, Oslo University and Haldor Topsøe A/S. Significant progress in fabrication and assembling technologies has been achieved in the field of electrical contacts between stack components (anodes to interconnect) and in electrode fabrication. Interesting results have also been achieved with an anode, enabling direct conversion of natural gas in an SOFC.

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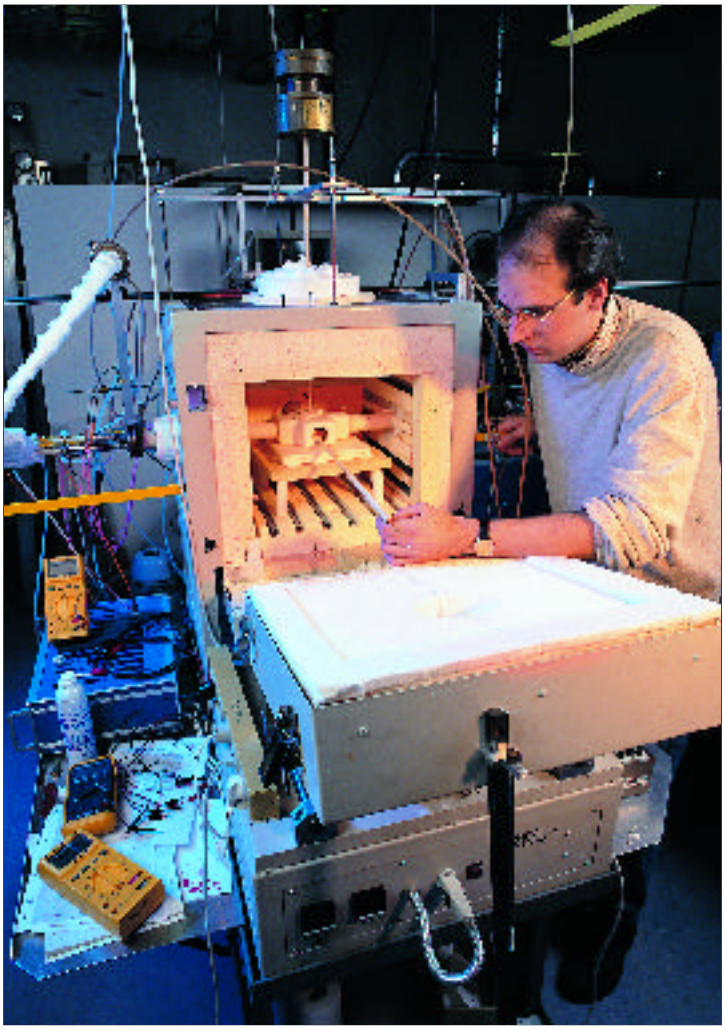

Experimental setup for testing of SOFC stack elements and small SOFC stacks. A stack element comprises a cell between two interconnects.

High-temperature superconductors
Development of methods for manufacturing and characterising superconducting materials.

Towards superconducting cables
Superconducting high-voltage cables are approaching realisation in a collaboration of NKT, the Technical University of Denmark, DEFU and Risø. The project is supported financially by the Danish Energy Agency, ELSAM and ELKRAFT. For superconducting cables, ceramic bismuth-strontium-calcium-copper oxide, BiSCCO is the superconducting material. BiSCCO is manufactured as a powder consisting of small flat flakes with a consistency resembling rolled oats. The superconducting current flows lengthwise only. It is therefore important for the flakes in a superconducting tape to lie parallel in the direction of the tape. A superconducting tape is manufactured by filling a silver tube with a diameter of – say – 20 mm with BiSCCO, starting with BiSCCO in a form called 2212, which refers to the chemical composition of the crystals. This version of the superconductor has a double-layered structure and a critical temperature of –193°C. At the same time, calcium oxides and copper oxides are added to the tube, which is then sealed, drawn to a wire, rolled, pressed and heat-treated a number of times. The result is a flat tape 150–200 micrometer in thickness. During the process, the crystals are aligned in one direction, with as many flakes as possible turned the same way. During the heat treatment a new version of BiSCCO is created, known as 2223. This means that the critical temperature risesto –163°C, significantly above the boiling temperature for liquid nitrogen. Several wires may be put in the same silver tube to form multifilaments. Sealed wires are drawn and cut into long sections. The wire sections are then inserted into a tube, which is sealed, drawn, rolled, pressed and heat-treated. The superconducting filaments thus become thin enough to bend without destroying the ceramic structure. On a newly established production line, tapes up to ten meters long can be made, and detailed studies can be made during each step of the process. The tape can be opened at any time, whereupon the ceramics can be studied using techniques such as X-ray dispersion, electron microscopy and infrared spectroscopy. Information can thus be obtained on the links between grain structure, quantity and type of impurities in the tape and the superconducting properties. The objective is to enhance the efficiency of superconducting tapes. The researchers have studied the superconducting tapes at the Deutsches Elektronen Synkrotron (DESY) in Hamburg. The synchrotron produces X-radiation which is so intensive, energy-rich and of such a short wavelength that the X-rays go through the silver, whereupon the rays are diffracted by the superconducting grains. The diffraction patterns show that the flakes tend to lie in the same plane as the lengthwise direction of the tape, but there are still large variations in how well they are aligned. There is much evidence to indicate that the flakes lie almost ideally close to the silver sheath, but the orientation is more random in the centre of the tape. This structure is of great importance for the superconducting properties of the tape. The main part of the current in the superconductor flows in the outermost 5–10 micrometers of the ceramics close to the silver sheath. If, by improving the production process, it is possible to increase the thickness of the superconducting layer, the critical current will increase correspondingly. That means it is possible to increase the strength of the current that can be sent through the tape. It is considered realistic for the critical current in the tape to be increased from the present 15,000 amperes/cm^2 to at least 50,000 amperes/cm^2.

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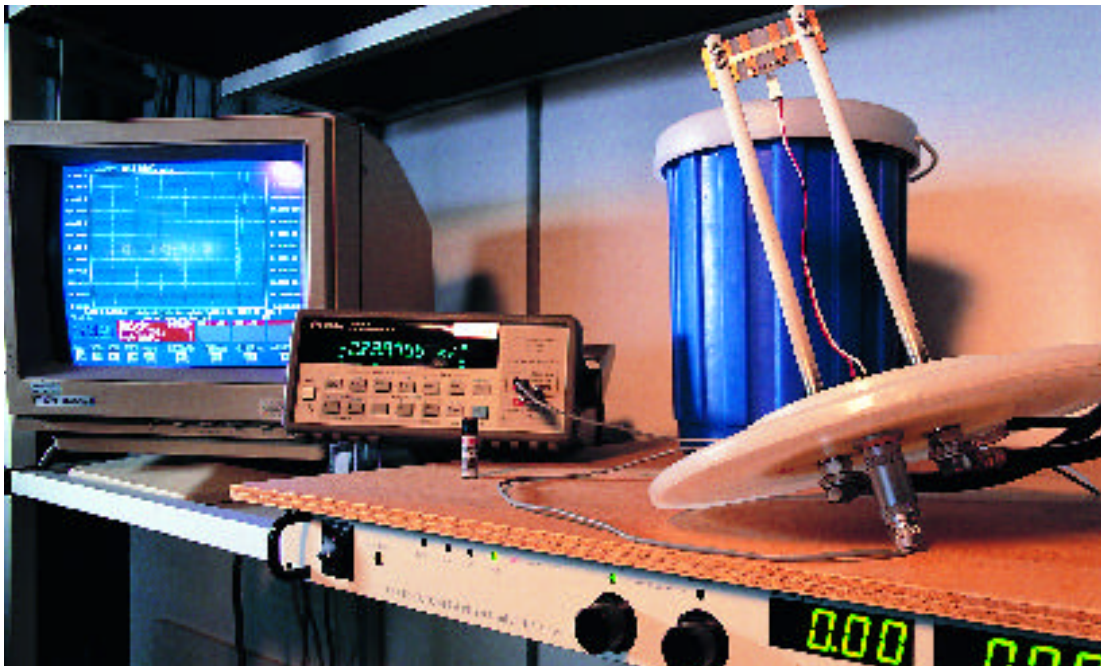

Equipment for measurement of critical current density in high-tempeature superconducting tapes.

New functional materials

Design, synthesis and characterisation of polymers and other materials with new physical and chemical properties, based on an understanding of their atomic and molecular structure.

Macromolecular materials chemistry

Design, synthesis and characterisation of polymers and other molecular materials based on an understanding of their composition.

The Danish Polymer Centre

The Danish Polymer Centre has now existed for more than two years as a collaborative venture of Risø, the Technical University of Denmark and eight partners in industry. Parts of the work described in the projects below have been carried out under the auspices of the Centre. Industrial collaboration projects in a variety of areas ranging from medical adhesives to high-performance injection-moulded components are progressing according to plan, thus adding to the industrial impact of the centre. The Centre receives funding from the Danish Materials Development Programme (MUP2).

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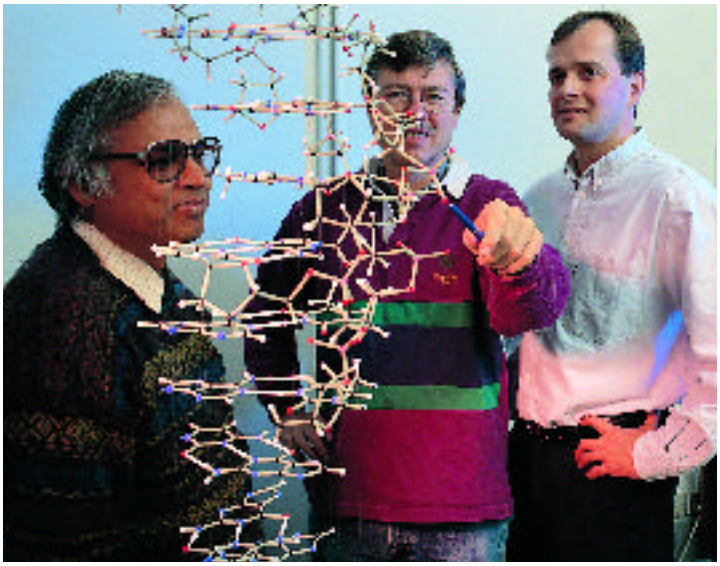
Soft materials with a promising future

Soft materials such as block copolymers are playing a growing role in technical applications such as thermoplastic materials. Block copolymers are materials that are composed of two different types of polymer materials chemically bound together. These mixed giant molecules behave in many aspects differently from simple polymer materials. At room temperature, they have a tendency to form ordered structures on the mesoscopic length scale that give them their visco-elastic properties. At high temperatures these materials become disordered and can be worked using injection moulding, for example. Theoretical predictions indicate that the transition from order to disorder is influenced by pressure. This was demonstrated in a small-angle neutron scattering (SANS) experiment where structural properties were investigated in-situ with the application of hydrodynamic pressure. In collaboration with Forschungszentrum Jülich, Risø has initiated a systematic study of the pressure dependence of block copolymers. A new block copolymer



The design of the DNO molecule for optical data storage is based on guidelines from the DNA double helix, shown here as a model. The three Risø scientists are from the left: P.S. Ramanujam, Søren Hvilsted and Rolf H. Berg.

New DNA-like molecule creates a breakthrough in optical data storage

Optical holographic storage is the future for a number of particularly demanding tasks such as, for example, the storage of satellite images, X-ray images, maps and fingerprints. Despite 15 years' intensive research, however, materials have not been developed that are suitable for practical use. It has certainly been possible to store thousands of holograms in very small spaces in various types of crystals and plastics. Some of these materials are too unstable, however, resulting in information loss, while others present problems in writing, reading and deletion of data. At Risø, a completely new material has now been created which not only stores very high quality holograms, but is also stable. At room temperature, the holograms can be kept for years, and they can withstand temperatures of around 180 degrees for several months. Heat stability is of great importance for practical optical data processing. At the same time, the new material is better than most plastic-based materials when it comes to writing and deleting data. In most plastic materials, the information is deleted by heating, erasing the whole disk in one operation. In the new material, writing and deleting alike are accomplished using laser light, enabling writing and deleting locally on the disk. This makes it possible, for example, to remove a single X-ray image that is no longer relevant without thousands of usable images being wiped at the same time. The material, called DNO, is constructed of small fragments of protein, so-called peptides. Peptides are designed to form a stacking pattern resembling the DNA spiral. Inside the spiral are photoactive chromophores resembling the genetic code of DNA. A hologram is read into the DNO material by illumination with a laser beam, which activates the pigments. The movement stops, however, when a co-ordinated process positions the pigment molecules at right-angles to the polarisation direction of the laser beam. This alters the way the light hits the material, and this local change in the refractive index contains the optically stored information. The hologram is read in the normal way by illuminating the material with a laser beam. The project is supported by SNF, MUP2 and The Danish Research Academy.

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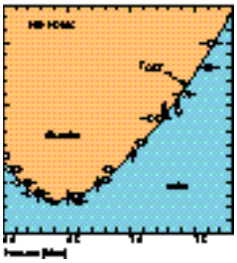

Temperature/pressure dependence of the phase behavior of a symmetric PEP-PDMS block copolymer.

system of poly(ethylene propylene) and poly(dimethylsiloxane), PEP-PDMS, revealed a most unexpected relationship between the order-disorder transition and pressure. Upon application of hydrodynamic pressure, the ordered phase melts, but at even higher pressures, a re-entrant ordered phase is observed. Block copolymers share important similarities with low-molecular amphiphilic molecules i.e. molecules that are soap-like with respect to ordered microstructures. Amphiphilic molecules such as surfactants, phospholipids and ionic soaps self-assemble in aqueous solutions into highly organised structures because of the hydrophobic effect. As the concentration of amphiphilic molecules increases, supramolecular aggregates form with a variety of ordered states. Block copolymer melts are a separate class of soft materials that spontaneously form ordered phases at a critical temperature. In attempting to get the link between block copolymer melts and solvated surfactants, Risø has collaborated with the University of Minnesota to study a new class of medium-sized block copolymers of poly(ethylene oxide) and poly(ethyl ethylene), PEO-PEE. The PEO-PEE polymer systems exhibit a variety of ordered phases. Transition from one ordered state to another occurs only when the lattice spacing is closely matched.

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Interfaces at the atomic level

The properties of interfaces between different materials are often determined by layers so thin that the atomic structure of the materials plays a crucial role. Adhesion of a polymer to a surface is a property in which the interaction energy between the surface and an organic material are important. Interfaces between inorganic materials – e.g. quartz and polymers – and between metals and single molecules have been studied using molecular mechanics and dynamics methods combined with quantum-chemical methods. Calculation of surface energies requires methods which treat both the surface and the organic material with precision.

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Magic numbers of proteins

An important objective in the chemistry and physics of macromolecules is to attempt to make large molecules (hetero-polymers) by using the tricks nature has developed in the course of a long evolution. The self-organisation of the chemical processes that nature masters is based on an interaction between enthalpy (basic forces) and entropy (the structural complexity of matter). One of the most challenging problems facing scientists in this context is protein folding: how can a large molecule consisting of thousands of atoms spontaneously and consistently fold up into a dense unit which has precise functional characteristics – all in a matter of seconds? A simple, physical theory and model based on symmetry principles demonstrates, surprisingly, that one key may be a sequence of magic numbers for the size of certain proteins and their frequency. The theory was confirmed with statistics from available databases.

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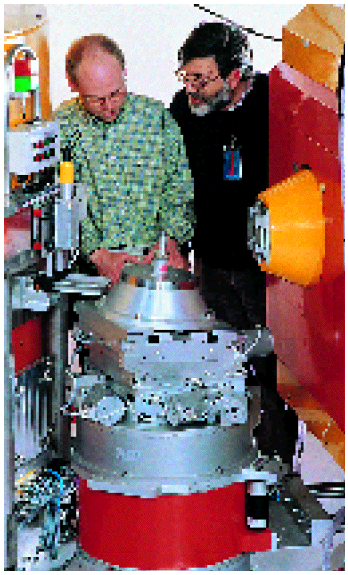
Microemulsions of oil and water

Microemulsions are homogeneous mixtures of oil and water with amphiphilic (soap-like) molecules situated at the interface between them. Phase behaviour and microscopic structure of microemulsions have major biological and medical relevance, and there are numerous technological applications of microemulsions, in particular in the food and pharmaceuticals industry.



Risø designs and build instruments for neutron scattering investigations. The picture shows a close up of the central part of the new RITA neutronspectrometer at DR3.

Microemulsions, where the soap molecules form long, flexible aggregates, are fascinating model systems for so-called equilibrium polymers. Their main difference from long polymer molecules is their limited lifetime, i.e. the fact that these aggregates are constantly breaking down and recombining, whereas classic polymers are firmly bonded. The structure of such microemulsions has been studied by small-angle neutron scattering (SANS) and computer simulations. This combination has provided us with detailed information on the local structure, flexibility and average length of the aggregates. The work is a collaborative venture with the Polymer Institute, ETH-Zürich, Switzerland.

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Magnetism and superconductivity

Properties of magnetic and superconducting materials, simulation of their atomic magnetism and the structure of the magnetic flux line lattice in type-II superconductors.

Magnetically ordered superconductors

Magnetic and superconducting states of a material are normally mutually exclusive. However, in a class of materials with the formula RNi_2B_2C, where R represents certain rare earths, antiferromagnetism and type-II superconductivity may coexist on the microscopic level. By exposing these materials to a magnetic field, and thereby generating a lattice of magnetic flux-lines, it is possible to study the interaction between magnetic ordering and superconductivity. In co-operation with Bell Laboratories, Risø has investigated the flux-line lattice in $ErNi_2B_2N$ using small-angle neutron scattering (SANS). This study shows evidence of microscopic interaction between magnetism and superconductivity. Moreover, the flux-line lattice has square symmetry, as opposed to the hexagonal lattice usually observed.

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New superstructures in high-temperature superconductors

The charge transfer leading to high-temperature superconductivity in the ceramic superconductor with the formula $YBa_2Cu_3O_{6+x}$ is strongly dependent on the oxygen stoichiometry and structural ordering. Using neutron

and high energy X-ray diffraction, Risø has observed new superstructures related to the formation of copper-oxygen chains in specific layers of the structure. Carefully prepared single crystals are used in the studies. The superstructures are characterised by alternating copper-oxygen chains that are oxygen-rich and low-oxygen. Experimental studies of the superconducting properties have shown that the chains have a strong influence on the superconducting transition temperature. Neutron diffraction studies have shown evidence of local crystal structure distortions related to the charge transfer.

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RITA: the next generation of neutron triple-axis spectrometers

RITA (Reinvented Triple-Axis Spectrometer) is an improved neutron spectrometer in use at Risø. It has many new technical details that significantly improve the opportunities for studying dynamic processes in the solid state. The first experiments using RITA demonstrate that the overall gain in efficiency can exceed one entire order of magnitude. RITA will improve the opportunities for studying new metals (so-called heavy fermions) and low-dimensional magnetic systems of increasing interest for fundamental physics and for studies into the fundamental mechanisms of high-temperature superconductivity.

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Surfaces and interfaces

Determination of atomic/molecular structure and functional properties of surfaces, interfaces and thin film and development of techniques for characterisation.

Focus on semiconductor surfaces

Interfaces between metals and semiconductors are of considerable interest for both fundamental and technological reasons in connection with the development of new electronic components. Most metals vapour-deposited on a semiconductor surface form complex interfaces. Exceptions are the semi-metals antimony Sb and bismuth Bi, where the interface to III-IV surfaces is normally regarded as being well-ordered without any restructuring of the atoms of the semiconductor material. Column-V metals on III-V semiconductors are frequently regarded as examples of ideal adsorbate-semiconductor heterojunctions. However, in a collaborative venture with the University of Hamburg, Risø has demonstrated that this simple picture is generally not true and that column V elements can induce significant restructuring of the substrate. This has been demonstrated in studies of a monolayer of bismuth deposited on the gallium/antimony surface.

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Contact problems between crystals

Computer simulation of interfaces between crystals of different materials is an important tool for understanding the complex phenomena observed. It is of relevance, for example, in tribology, corrosion protection, lubrication and many other technological applications. Risø has investigated a model system of one alkali chloride on another for which the interface is complex, while the interatomic forces are well known. Our simulations provide a new interpretation of the interfacial structure, which can be verified by X-ray scattering. The method has the advantage that quite large systems can be simulated, and, consequently, the statistical properties can be assessed.

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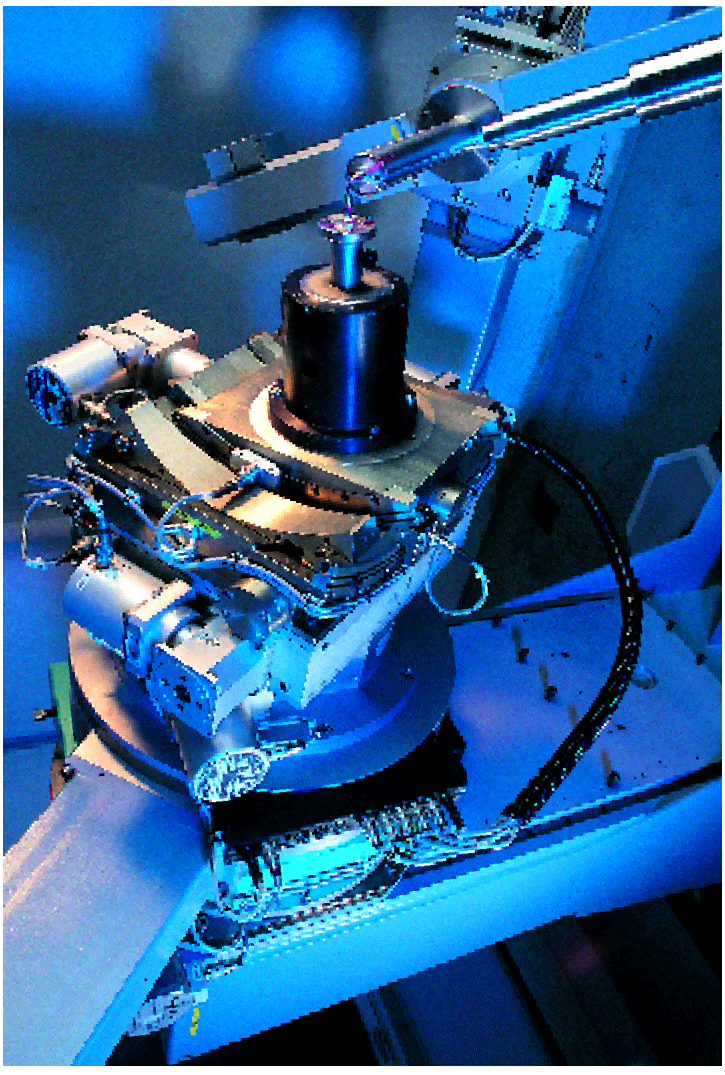
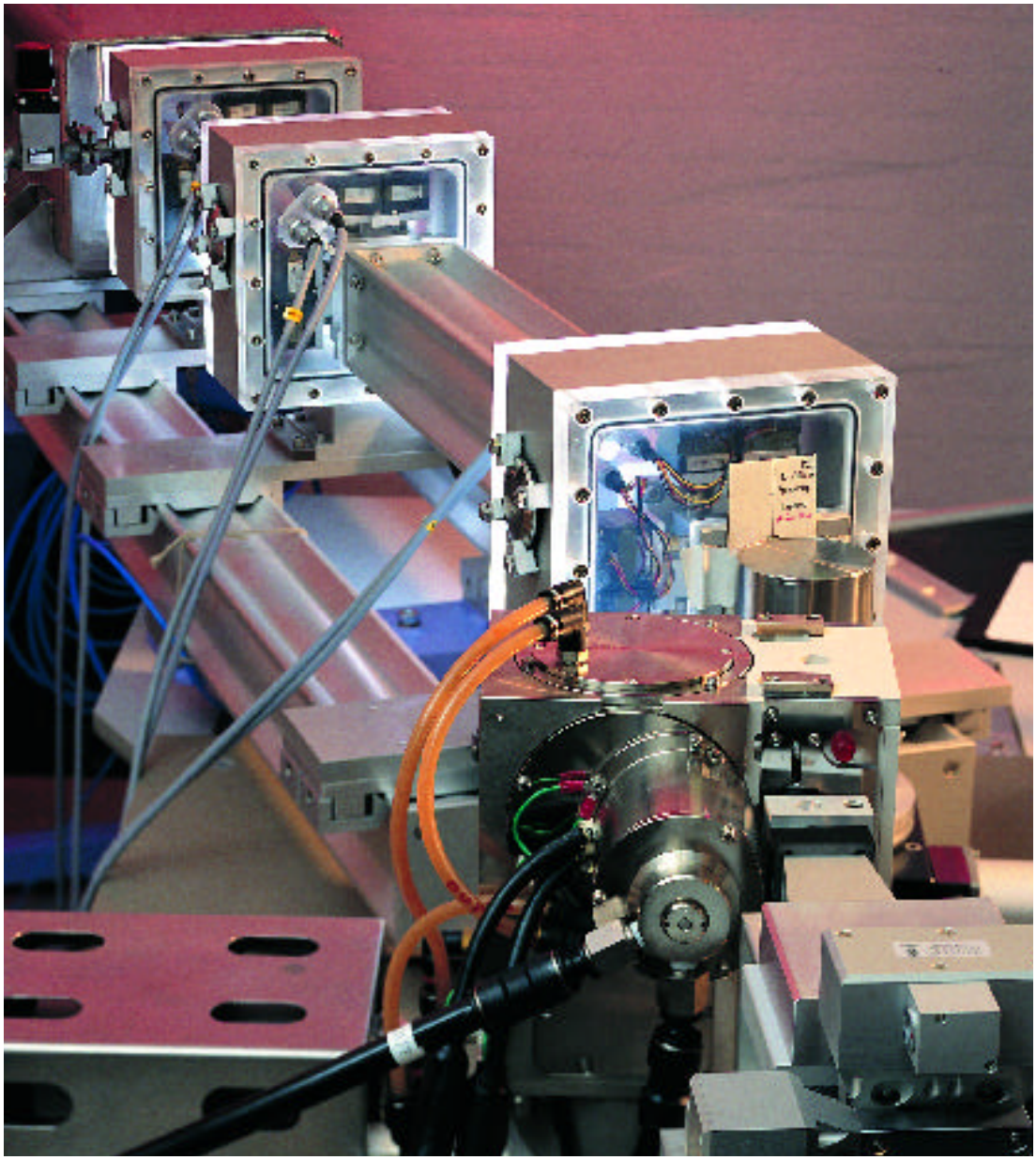


Commissioning of a new X-ray diffractometer dedicated to investigations of surfaces. The instrument is installed at the synchrotron radiation laboratory HASYLAB in Hamburg.



Small-angle X-ray scattering apparatus for investigations of polymers.

Nanoclusters in copper film

The smallest existing crystals contain only from tens to hundreds of atoms, and in such small crystals, their size and external shape become important for their properties. These so-called nanoclusters are studied both for the interest of their optical and electrical properties and because they play an important role in epitaxial growth of thin films. Using synchrotron X-ray diffraction, Risø has measured the detailed atomic structure of such nanoclusters and the strain field which determines their size and shape. A particular example is a new type of nanocluster in copper (Cu) films grown on nickel (Ni) substrates. Here the clusters are embedded inside the copper (Cu) film, and they are believed to constitute a new, general and important phenomenon in epitaxial film growth.

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Magnetic superlattices

Using advanced deposition techniques such as Molecular Beam Epitaxy (MBE), it is now possible to design magnetic materials at the atomic level. These materials are important as future magnetic data storage media. In collaboration with Oxford University, Risø has studied the magnetic properties of superlattices fabricated from the rare earth metals, using a mixture of neutron and X-ray scattering. In their pure state, the rare earth metals display a rich variety of magnetic structures, which have proven to be capable of unexpected modification in the superlattice. In superlattices formed from magnetic holmium and non-magnetic scandium, the helical magnetic order of the holmium is primarily confined to lie within the holmium layers. This observation contrasts with the case of superlattices formed from holmium and other non-magnetic elements.

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Optics and sensor systems

Development of systems, structures and materials for optical measurement and information processing based on diffractive optics and nonlinear dynamics.

Optical diagnostics and information processing

Development and exploitation of methods of optical measuring and information processing for industrial applications.

Sensors, measuring systems and information processing

Risø is involved in a number of collaborative ventures on sensors as well as measurement and vision systems. A project in collaboration with B&O Technology aims at non-invasive glucose measurements of blood. The method is based on the spatial distribution of backscattered light. A diffusion model for light propagation in tissue has been established.

Kamstrup A/S is a major manufacturer of automation equipment for measurements in district heating systems. Together with this company, through an industrial post-doctoral project Risø is developing new measurement schemes based essentially on optoelectronics.

Ibsen Micro Structures A/S is a development company located in CAT with diffractive optics and holographic elements as its core business. Risø collaborates closely with this company on the development of diffractive elements and miniaturised sensors. A series of optically based systems related to mechanical measurements has been investigated with a view to possible industrial applications. These systems rely on optical processing of speckle patterns diffracted from surfaces undergoing a translation or a rotation.

Research into active vision and pattern recognition is being carried out via a number of EU projects. A new active vision system has been developed and is being used in connection with a EUREKA project to find and classify labels on containers. The project is being carried out jointly with the Danish companies Rambøl A/S and Liisberg ApS.

Risø is developing a number of other concepts in areas ranging from finding parts in old TV sets to identifying and classifying the operational states of waste incinerators. Risø has participated in a feasibility study on mine detection in connection with clearing of mines in war zones. The project was commissioned by the Ministry of Foreign Affairs, and the Centre for Advanced Technology was responsible for project management. Several methods and technologies were examined in the project. It did not prove practical to implement the methods investigated by Risø within acceptable price, weight and space

Lossless light labelling

When articles are being produced on conveyor belts, they need to move at high speed. Beer cans, for example, need to be marked with production information as they travel along, which has to be done at a high speed. A quick and effective way is to make a mask, a kind of slide image, containing the information. The slide image is projected onto the can and, if the light is strong enough, the image on the can will not only be visible, a permanent imprint will be the result. This requires a high-energy laser, however, and not just an ordinary lamp as found in a slide projector. The problem is that in simple imaging systems most of the laser energy goes into the mask instead of being projected onto the beer can. The result is that extremely powerful lasers have to be used and the mask must correspondingly be capable of withstanding the very high energy levels. This, in turn, makes the process expensive and in many cases impossible to implement, just as it leads to serious energy losses. Risø has developed an effective method for solving this problem. Patents for this process have been applied for, and the process is now being developed for practical application in a collaborative project with Hamamatsu Photonics Central Research Laboratory in Japan. The underlying idea is to use a special kind of phase-coding of the pattern to be imaged onto the item. In normal masks, e.g. a slide, the image appears by regulating the amplitude of the light, but this type of regulation uses energy. This may cause the slides to heat up and bulge in the projector if they are left there for too long. The advantage of using a phase mask is that it does not absorb energy. On the other hand, the image will not be visible. The phase distribution is converted into an amplitude distribution and thus into a visible image on the beer can using a so-called non-absorbent generalised phase contrast filter. The method may reduce energy consumption by one or two orders of magnitude, which makes the projection of images and patterns usable in many applications where it has hitherto either been impossible or economically out of the question.

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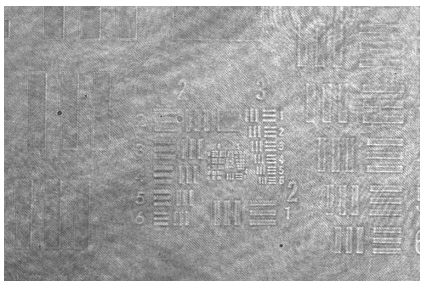
a)



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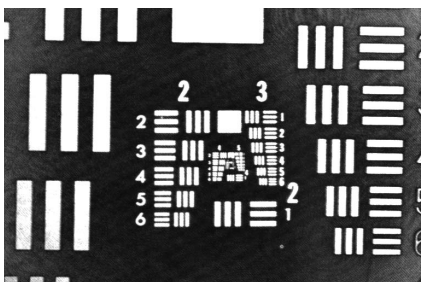

Detected images obtained from a binary encoded π-phase PAL-SLM input pattern: a) simple imaging with no application of a phase contrast filter; b) imaging obtained when a π-phase-shifting phase contrast filter is situated in the Fourier plane.

FTIR diagnostic. An infrared fibre-optic probe has been developed for measuring the gas temperature and gas composition in furnaces.

limitations. The best results have been obtained with earth-penetrating radar systems developed at the Technical University of Denmark.

Gas and particle temperatures are measured in combustion systems with an innovative Fourier transform spectroscopy method. The system is used for measurements in biomass and coal-fired furnaces. Part of the work is done in collaboration with Danish electric power companies. Fourier transform infrared spectroscopy is furthermore being used for the characterisation of powders consisting of superconducting particles in collaboration with NKT Research Centre.

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Optical materials

Development, fabrication and study of optical materials for sensors and processes.

Optical materials for information storage and diffractive elements

Holographic data storage is a promising technology that may come to fruition in commercial use by the beginning of the 21st century. Holographic media will have ultra-high capacity data storage with fast data access and transfer times. In holographic memory storage, capacities of 100 Gbytes/cm^3 are possible, with transfer rates of more than 1 Gbyte per second. Finally, the access time for data is approximately 10 µs, which is at least two orders of magnitude faster than for conventional storage media. Risø is studying the basics of optical data storage in organic as well as inorganic optical media. Among the organic media, side-chain liquid crystalline azobenzene polyesters have been investigated (see also discussion under Macromolecular materials chemistry). Another organic material of which the optical properties have been studied is DNO (see also discussion under Macromolecular materials chemistry). Inorganic photorefractive crystals are another very promising candidate for holographic storage. Up to 15,000 holograms can be stored in one cubic centimetre of these materials. Each hologram is stored by recording with a plane reference beam and an image beam. An automated digital holographic recording device has been constructed for investigations. Multiple holograms are recorded in an iron-doped lithium niobate crystal by means of angular multiplexing, i.e. each new hologram is recorded at a slightly different angle from the preceding one. A spatial light modulator is applied to compose digital images in the photorefractive crystal. The stored information is detected with a CCD camera and a new effect – nonlinear cross talk – is analysed on a personal computer with a framegrabber. The nonlinear cross talk is a phenomenon that occurs due to nonlinearities in the photorefractive crystal. This effect imposes some fundamental limitations on the storage density and the capacity of the system. Risø has shown experimentally that this effect can lead to 90 % cross talk between neighbouring holograms stored in the medium. The effect also influences response times for erasure and build-up of a specific hologram. The purpose of the experiments is to establish how cross talk is controlled and how it influences the data storage capacity.

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Nonlinear optics

In recent years there has been increasing interest in nonlinear optics, as many potential applications are expected from the materials that exhibit this effect. As opposed to most other nonlinear optical materials, the photorefractive materials exhibit their nonlinear optical effect at very low light intensities, which makes them very suitable for commercial systems as production costs will be low. Two new nonlinear effects have been investigated, namely the so-called photorefractive parametric oscillation and magneto-photorefractive effects. Photorefractive parametric oscillation appears in a photorefractive crystal when holographic information is stored in the material. For certain experimental situations, the hologram that is stored becomes unstable and new holographic structures arise, referred to as parametric holograms. It is important to be able to control these processes as they can destroy the optical information stored in the crystals. The magneto-photorefractive effect is investigated in the photorefractive crystal $LiNbO_3$, one of the most promising photorefractive materials. It has recently been demonstrated that by applying a magnetic field to the medium, the strength of the stored information can be significantly enhanced – by up to 60 %. A theoretical model developed reveals that the enhancement is due to the so-called magneto-photorefractive effect, in which certain electrons interact with the magnetic field and thereby contribute to the formation of the holographic image.

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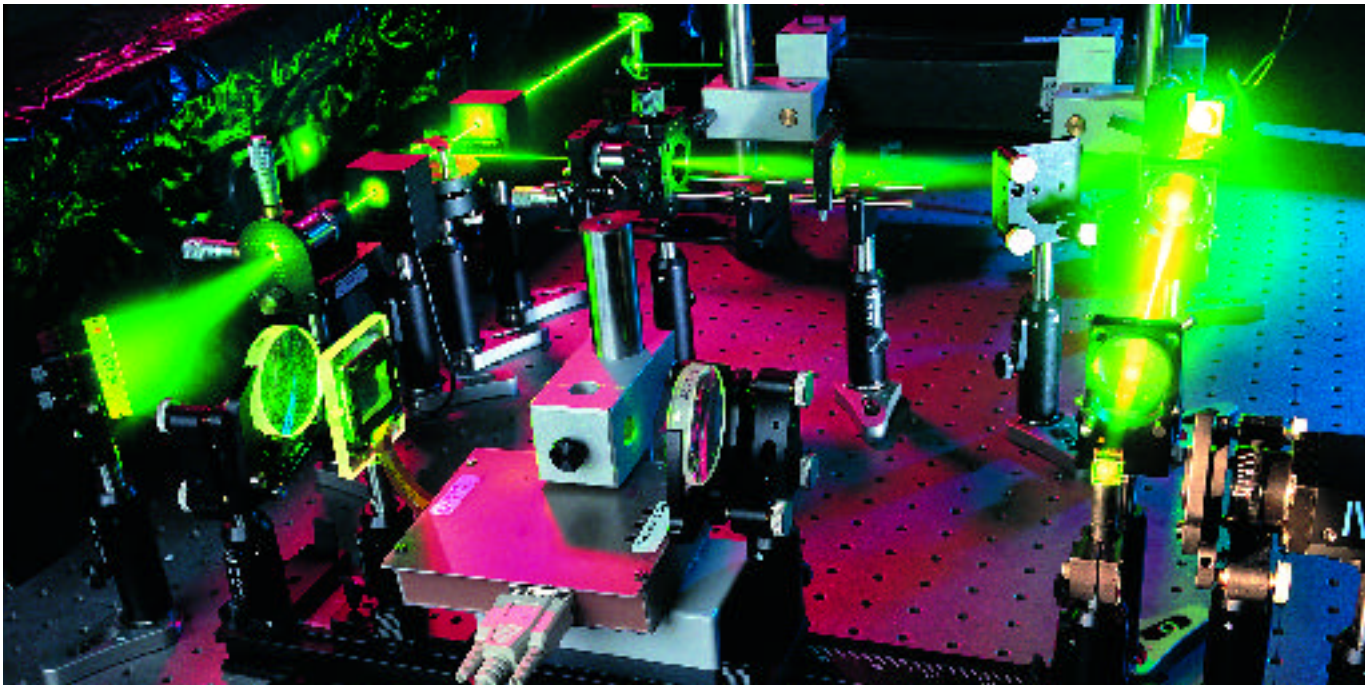

An automated holographic recording device used for investigating fundamental limitations in photorefractive data storage. In the set-up multiple holograms are recorded in an iron doped lithium niobate crystal using angular multiplexing. Each hologram is written with one reference beam incident at a given angle and an image bearing object beam. A spatila light modulator is used to compose digital images in the photorefractive crystal. The stored information is detected with a CCD camera and the crosstalk between holograms is analysed on a personal computer with framegrabber.

Plasma and fluid dynamics

Description of nonlinear flows and propagation of electromagnetic radiation in systems with complex geometry for industrial applications and future fusion energy. The fusion research is performed as a contribution to the joint European fusion programme coordinated by Euratom.

New laser diagnostics for fusion research

Based on a measurement technique developed at Risø, a new laser diagnostic system has been constructed for use in fusion energy research. The diagnostics will be used to measure detailed properties of plasma turbulence in the 100 million-degree hot interior of large-scale magnetic fusion experiments. Compared with existing diagnostics, the new method has the great advantage of allowing spatially resolved measurements. This ability will give fusion researchers a long-sought-after tool for the investigation of complex transport properties inside a magnetically confined plasma. Risø has signed a formal agreement on collaboration concerning studies of plasma turbulence with the Institut für Plasma Physik in Garching, Germany, and in 1996 the laser diagnostic was installed on the Wendelstein 7-AS Stellarator, where it is currently being tested.

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Self-organisation and pattern formation in fluids, plasmas and optics

A number of dynamic processes in different physical systems exhibit an ability for spontaneous pattern formation through self-organisation. Self-organisation plays an important role in the evolution of turbulent flows, but may also be controlled and utilised in, for example, the development of new optical devices. From 1993, Risø has co-ordinated a framework programme on nonlinear dynamics in continuum systems supported by the Danish Natural Science Research Council (SNF). This programme, which also encompasses activities at the Technical University of Denmark, has led to a very active exchange of theoretical, numerical and experimental results obtained in a number of areas including fluid dynamics, plasma physics and nonlinear optics. In 1996, new experimental and numerical results were obtained for optical vortices and elliptical solitons in photorefractive crystals. In the fluid laboratory, pattern formation in a circular shear layer and stability properties of isolated vortices were studied in a rotating fluid. Furthermore, new theoretical and numerical results were obtained for the nonlinear interaction of light with media possessing different types of nonlinearity.

In the studies of nonlinear dynamics in fluids, plasmas and optical media, supercomputers are a important tool. Large supercomputers allow detailed computations of complicated dynamic processes to be carried out, and the effects of changing various physical parameters to be tested directly. Risø has developed highly accurate and efficient methods of calculation for detailed studies of the basic phenomena involved in various types of self-organisation, pattern formation and turbulence. In 1996, several of the programs have been optimised for and implemented on a parallel supercomputer at UNI-C. New results were obtained for the mixing of particles caused by the interaction of individual vortices, and for boundary layer dynamics in two-dimensional systems.

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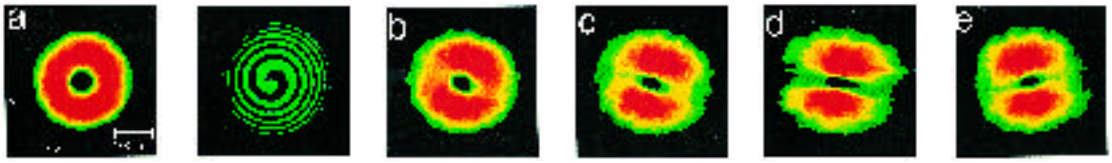
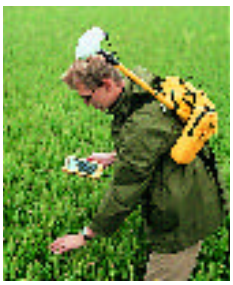


Experimental measurements of an optical vortex.

Plant production and ecology

Development of new plant properties and biological and genetic engineering methods for plant breeding and plant production with a view to improving products and restricting the adverse impact of agriculture on the environment.



Position and characterisation of patogens and weeds is mapped with GPS-equipment.

Plant-microbe symbioses

Establishment of fundamental knowledge of controlling the interaction of plants and symbiotic microorganisms.

Interaction of fungi and plants saves fertilisation

Symbiosis between mycorrhizal fungi and plant roots enhances nutrient uptake by plant root systems and is therefore an important resource in sustainable crop production systems. Maximum exploitation of this plant-fungus association will depend on a thorough understanding of its functioning. Risø has developed methods for studying the fungal nutrient transport from soil to plant and has established a collection of isolates of mycorrhizal fungi differing widely in transport characteristics. Excised mycelium of these isolates has been used in physiological studies of their phosphorus and nitrogen uptake. These in vitro studies will be complemented with molecular and genetic studies in order to identify the rate-limiting processes in mycorrhizal nutrient transport and to reveal the regulation of these processes.

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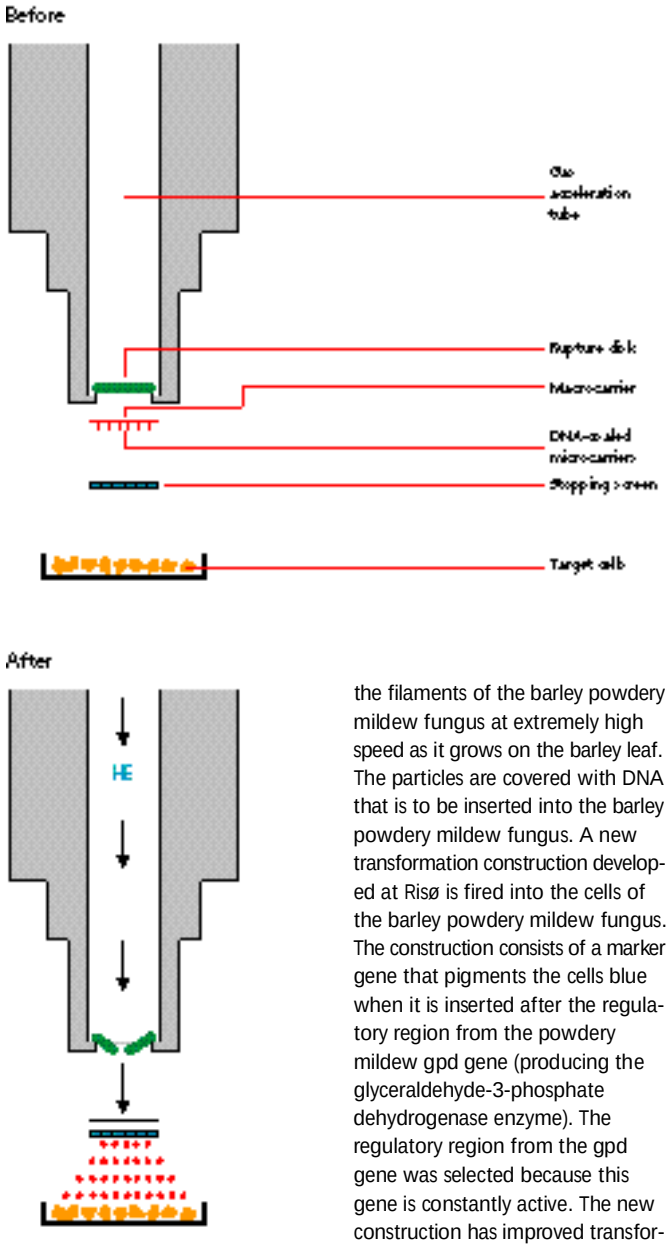
Microbes supply nitrogen to plants

Sustainable agriculture requires optimal utilisation of plant-microbe symbioses. Soil bacteria of the genus Rhizobium may bind atmospheric nitrogen, and pass it on to the plant. Knowledge on the regulation of this symbiosis is, therefore, essential. The symbiosome membrane separating plant and microbe plays a central role in this regulation, as all compounds exchanged between symbionts must pass this membrane. Risø has identified an ammonium transport mechanism within the symbiosome membrane making use of energized membrane vesicles. This mechanism facilitates the transport of nitrogen from the microbe to the plant, and it is driven by a membrane potential and by the pH of the



Principle in transformation using a gene gun.

Transformation of the barley powdery mildew fungus

To identify and analyse powdery mildew genes of importance for infection of the barley plant, a transformation system is necessary. Transformation is a technique for inserting foreign DNA into organisms. The barley powdery mildew fungus is transformed using a so-called particle gun. Ultra-small particles are fired into the filaments of the barley powdery mildew fungus at extremely high speed as it grows on the barley leaf. The particles are covered with DNA that is to be inserted into the barley powdery mildew fungus. A new transformation construction developed at Risø is fired into the cells of the barley powdery mildew fungus. The construction consists of a marker gene that pigments the cells blue when it is inserted after the regulatory region from the powdery mildew gpd gene (producing the glyceraldehyde-3-phosphate dehydrogenase enzyme). The regulatory region from the gpd gene was selected because this gene is constantly active. The new construction has improved transformation efficiency significantly. The whole gpd gene was cloned, sequenced and characterised for the purpose of isolating the regulatory area. The sequence was used in a phylogenetic study including the gpd gene from 16 additional fungi. In this analysis the powdery mildew fungus falls into the group of ascomycetes. A study revealed that the powdery mildew fungus is more flexible in choice of DNA base pairs than previously described for filamentous fungi.

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interface. The transport mechanism concentrates ammonium 3–4 times inside vesicles compared to outside and, within physiological relevant ammonium concentrations, the mechanism shows an unsaturable capacity for ammonium transport that may account for the needed transport in functional plant-microbe symbiosis.

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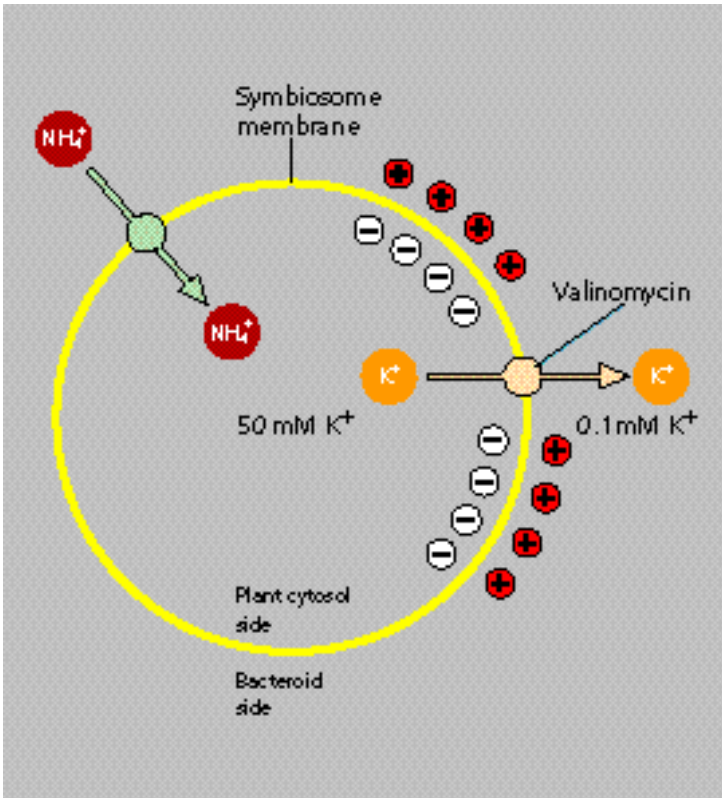

The uptake of ammonium by symbiosome membrane vesicles is facilitated by the generation of an electric potential across the membrane. The potential is generated when the potassium transporter valinomycin is added to vesicles with a high internal concentration of potassium. Valinomycin carries positively charged potassium ions across the membrane along the potassium gradient leaving a negative net charge behind.

Resistance biology and plant genetics

Production of genetic knowledge to improve plant properties, and knowledge of the biological interaction between crops, other plants and pathogens with links to agricultural land.

Risks of growing transgenic plants

A possible risk in cultivating transgenic crops is spontaneous dispersal of the transgenes from crops to related wild species, with unknown environmental consequences. At Risø we have studied the possibilities of transgene dispersal between oilseed rape (Brassica napus) and the related weed B. campestris. The species hybridise readily, but closer investigation of individual life stages has shown that conditions during pollination, seed development and germination influence the extent of transgene dispersal. In evaluating the likelihood of two species hybridising, controlled crosses are often performed between the species where flowers are pollinated with pollen from either the crop or weed. In nature, flowers will usually receive a mixture of pollen from the two species, and when the two types of pollen compete for pollination, or when hybrid seeds compete with 'normal' seeds within the fruits, this may lead to a relatively lower development of hybrid seeds. This has been shown to be the case for hybridisations between oilseed rape and B. campestris. Whereas most earlier studies have shown that it is easier to produce hybrids on oilseed rape, we found that hybrids are more readily produced on B. campestris when pollinated by pollen mixtures. When hybrid seeds are produced spontaneously in nature, their germination has a major influence on the probability of establishment of hybrid plants and, therefore on an eventual transfer of transgenes. Studies at Risø have shown that hybrid seeds of oilseed rape and B. campestris germinate readily, unlike seeds from B. campestris where the seeds have a pronounced dormancy. Dormant seeds germinate over a relatively long period of time, and for this reason B. campestris is a persistent weed. Hybrid seeds, in contrast, germinate shortly after they fall to the ground, and in a traditional cultivation system with rotation they are therefore likely to be eliminated by weed management. Back-crossing of hybrids to B. campestris plants is thus limited, a factor that decreases the transfer of transgenes.

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Plant ecosystems and nutrient cycling

Determination of the structure, function, processes and dynamics of agricultural and forestry ecosystems and development of forecasting models of their responses to changing conditions.

Sustainable agriculture

To improve the sustainability of agricultural production, it is necessary to develop methods which use resources more efficiently. For example, recycling of nutrients from urban to agricultural areas could be increased, and biological management of soil-nutrients could be integrated into cropping systems. Maintaining and improving soil fertility and the quality of the environment must be in focus when developing new methods. The application of organic matter, e.g. crop residues, organic fertiliser and sewage sludge to cultivated soils contributes nutrients for subsequent crops and energy/carbon for the microbial transformation of nutrients and formation of humus. Studies on the decomposition and transformation of carbon and nitrogen from crop residues and organic fertiliser using stable isotopes show that factors, e.g. seasonal conditions, spatial distribution in the soil and particle size of the organic matter, can be manipulated to improve the utilisation of nutrients in the material.

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The CLIMEX greenhouse. An experimental facility to study the greenhouse effect at Risdalsheia, Grimstad, Norway.

European forests in the climate of the future

In 1996 Risø participated in the EU project CLIMEX, which is studying the response of forested catchments to a climate of the future with increased CO_2 content in the air and higher temperatures. Research teams from the UK, Norway, Sweden, The Netherlands and Denmark are working on the experiment at the same forested catchment in southern Norway. Two experimental plots there are covered with 1200 m^2 greenhouses over the forest and are used to simulate atmospheric conditions with increased CO_2 concentrations and higher air temperatures. The objective of the project is to measure changes in plant CO_2 uptake and gas exchange, and to measure changes in forest growth and biogeochemical cycling of elements in the ecosystem. The ultimate purpose of the project is to develop models linking terrestrial and aquatic responses to global climate changes, and to upscale the results to an evaluation of the importance of global climate changes for European forests. The project runs until 1999.

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Plants and pollution

Polycyclic aromatic hydrocarbons (PAH) are a group of tar compounds in the environment not generally considered to constitute a hazard to fauna and flora. Normally 1–10 % of the compounds are the nitrogen-containing azaarenes, and at Risø we have studied one of these compounds, acridine. In an experiment with barley, rye-grass, rape, cornflower, and navew – the latter two being common weeds in Denmark – we found a toxic effect on most plants at soil concentrations five times lower than recommended for PAHs in general, which is 5 ppm. At 10 ppm, navew and cornflower seed did not germinate at all. Barley and rye-grass seem to recover more or less from the effect at the early stage. Acceptable concentrations should be reconsidered.

A new method for identifying tyre residues and particles of asphalt shows that, close to motorways, the quantity of asphalt particles in the soil falls exponentially in proportion to the increased distance from the road. The amount becomes constant approximately 20 meters from the road for asphalt particles, but at a shorter distance from the road for tyre particles. Small particles have a longer lifetime in the air, and only particles larger than approximately 20 micrometers are deposited by the side of the road. No conclusions can be drawn based on the provisional results from the plant samples. However, there is a trend towards tyre particle concentrations on the upper and lower surfaces of leaves being equally great. This, in turn, is a consequence of particle size, because small particles are transported and deposited by diffusion and not by means of gravity.

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Trace elements and organic compounds

Clarifying the occurrence and transport of trace elements and organic micro pollutants in plants, plant products, and the human food chain.

Is the method of cultivation important to the element composition of plants?

In a project under the FØTEK2 programme, trace element profiles are being studied in various agricultural and gardening crops cultivated biologically and conventionally using pesticides and artificial fertilisers. The

purpose is to investigate whether the two very different methods of cultivation influence the element composition of the plants. Of particular interest are elements that so far have gone unnoticed in the context of nutrition because they are normally found in extremely low concentrations, as well as elements that are traditionally regarded as essential or toxic. Samples analysed for more than 60 elements have been collected around Denmark, where crops have been cultivated in different types of soil. To ensure that results will be influenced only by cultivation methods, and not by genetic differences, the study has been restricted to only one kind for each crop type. The analyses are carried out in clean room using a high resolution inductively coupled mass spectrometer. This particular method of analysis makes it possible to carry out multi-element analysis at very low concentrations.

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The fate of organic soil contaminants

In evaluating the risk for man and the environment associated with contaminated soils, it is essential that we can follow the fate of the contaminants. Consequently, Risø has initiated investigations on the uptake of organic contaminants (a plasticizer and a group of detergents) in crop plants (barley and rape) from sludge amended soils. The aim is to implement reliable methodology for greenhouse uptake experiments and for subsequent trace level chemical analyses, and also to provide data for evaluation of existing models describing plant uptake. Furthermore, development of methods for determining volatility and leacheability of petroleum hydrocarbons has been initiated. Here, the aim is to enable predictions of the suitability for in-situ remediation by bioventing at gasoline contaminated sites, and to assess the risks associated with residual soil contamination after completed remediation. Plant uptake studies are done by contract with the Danish Environmental Protection Agency, whereas the development of methods for soil contaminant mobility assessments are done in co-operation with Danish consultants and development firms active in soil remediation by contract with the Danish Ministry of Business and Industry.

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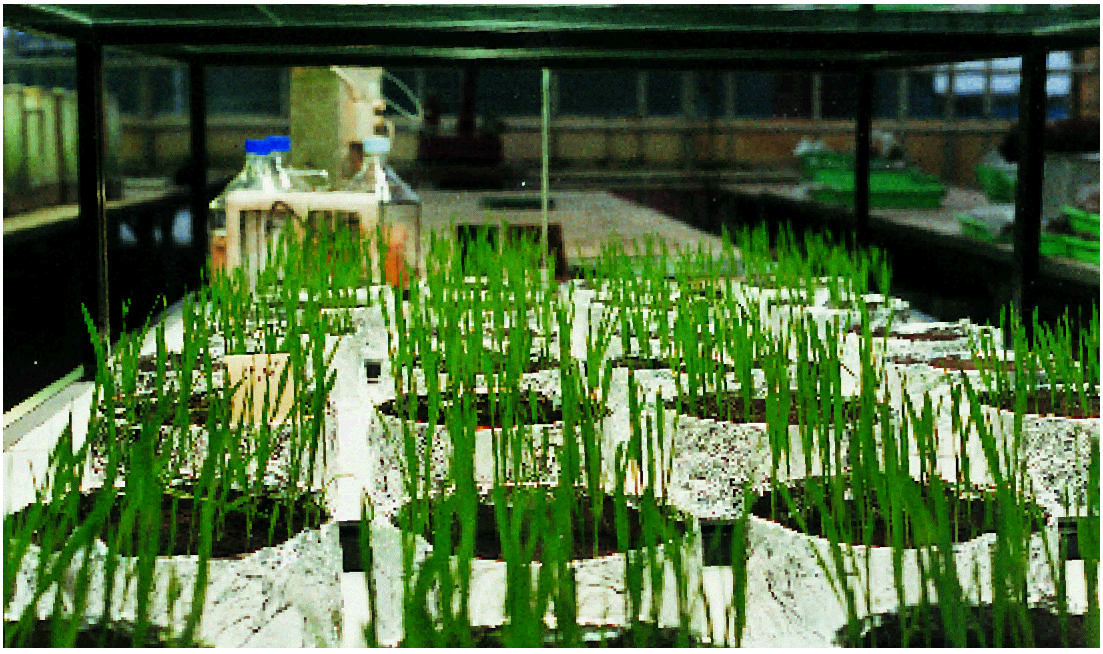

Greenhouse experiments with growth of barley to investigate the uptake of organic contaminants from sludge.

Systems analysis

Development of technical and economic optimisation and risk management methods for complex industrial and energy systems, with emphasis on environmental considerations and human factors.

The Danish company MARIDAN and Risø collaborate on the control system for a mini-submarine. Here the mini-submarine MARTIN is launched for tests in Roskilde Fjord.

Industrial safety and reliability

Development of methods to analyse the safety and reliability of technical systems.

An intelligent unmanned mini-submarine

In a joint project with the company MARIDAN and the Institute of Automation at the Technical University of Denmark, the control system of an unmanned mini-submarine is being designed. This will enable the vehicle to perform autonomous surveys of pipelines and power cables on the sea bed. The power company SEAS and the surveying company Svitzer are monitoring project development. The research is financed by the Danish Energy Agency, the Danish Technical Scientific Research Council (STVF), Danish Academy of Technical Sciences (ATV) and the Ørsted fund. To enable autonomous execution of the inspections, it is necessary for the control system and other equipment of the submarine to be highly reliable under normal and abnormal operating situations. Risø's part in the project involves a functional analysis of the tasks to be performed by the control system. The analysis serves as an aid in the design of the control system. The analysis also forms the basis of an automatic diagnostic function which can diagnose failure situations arising from internal failures in the submarine, or from causes such as obstacles in the path of the submarine. The concept of using an unmanned autonomous vehicle in sub-sea inspections is promising, as it will lead to a long-term reduction in costs compared with current methods using divers or vehicles connected by cable to a mother vehicle. An autonomous vehicle will be far less dependent on weather conditions and will presumably also require a less sophisticated mother vessel.

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Safety systems for wind turbines

Risø's work on the reliability of wind turbine safety systems is carried out in a Danish Energy Agency project and an EU project. The projects have resulted in a methodology for analysing the reliability of the safety systems of wind turbines and a database for reliability data of wind turbine components and equipment. The methodology and database provide advanced on-line reliability analysis of the two wind turbine safety systems included in the project. The system will also have great potential for design and maintenance planning in other technical systems. In a new project, quantitative risk assessment of wind turbines is being undertaken, where safety levels are recommended based on constructional standards and accepted safety levels for industrial and transport activities in European countries. Participants in the project are BONUS Energy A/S, NORDTANK ENERGY GROUP A/S and ELSAM-PROJEKT A/S.

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Safety and maintenance of process plants

Risø has developed a database analysis tool for decision-making support in relation to process plant maintenance and safety. It is based on the repair reports from twelve nuclear power plants in Sweden and Finland. These use a common format for repair reports that are sent to and stored in a joint database in Sweden. The results obtainable using the new tool relate to quality, costs, failure rates, the relationship between preventative and corrective maintenance and breakdowns. The tool has been tested at the nuclear power plant at Barsebäck in Sweden. It will also be implemented in a joint database in Sweden, where it will be remotely accessible via terminals by all twelve nuclear power plants contributing to the database.

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Interaction between humans and machines

Development of methods for analysing the interaction between human beings and advanced technical systems for the purpose of establishing concepts for the safe and effective execution of complex work tasks.

Safety-critical ship navigation

Ship collisions and foundering result mainly from human error combined with factors such as poor visibility, limited manoeuvring space and unfavourable current, wind and water depth conditions. Typical human errors include poor situational awareness on the bridge, miscalculation of the vessel's response to rudder and engine thrust and misunderstandings in communication between crew members. In a project under the EU Transport Programme, Risø and the Danish Maritime Institute are analysing crew work during complex navigation in coastal waters. The main purpose is to develop methodology for simulating ship handling performed by more or less highly-trained personnel. Input for simulations of this kind is obtained from experiments in ship-bridge simulators at the Danish Maritime Institute.

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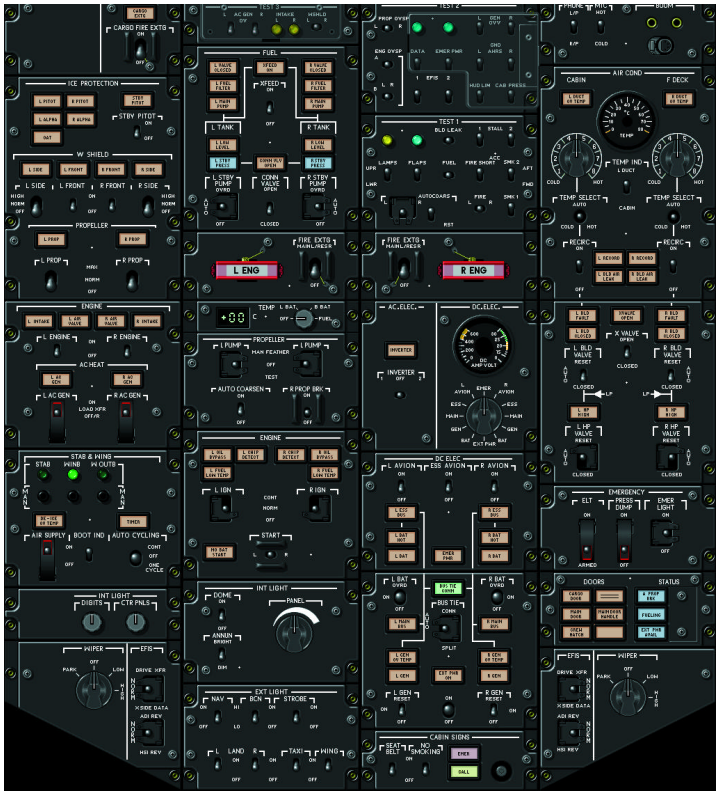
IT support for product development and collaboration

Industrial product developers from different professional backgrounds, with expertise in different fields and belonging to different departments collaborate across the organisation to make complex design decisions. This places great demands on the ability of the personnel to coordinate their activities, and involves the collection and evaluation of large amounts of information about end-user needs and options in relation to getting new products manufactured, marketed, distributed, serviced and disposed of at the end of their lifetime. In a project supported by the Danish Research Council for the Humanities, Risø collaborates with Danfoss A/S and universities in the USA, Canada and the UK to provide product developers with information technology that will effectively support their information needs, search behaviour and co-operative decision-making. The aim is to establish requirements for an integrated IT system for retrieval, indexing and storage of information using Internet facilities. A series of field studies of which coordination activities were performed in another investigation. Based on these studies, Risø has established a conceptual framework for analysing coordination work and has established a set of detailed requirements for IT coordination support. Several prototype computer-based coordination mechanisms have also been developed. In these proto-



New type of flexible training simulator: Aircraft overhead panel (Saab 340) represented on a 1:1-size computer projected, touch sensitive screen. Indicators and knobs are graphical objects and pilots can activate knobs by touching the screen. A single simulator can thus be used to represent many types of aircrafts.

types, a high degree of flexibility is essential, with the users themselves being given opportunities to construct their own support mechanisms.

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Touchscreen-based controls

When developing training simulators in which pilots can train checklists and procedures it is much more cost-effective to use computer graphics and touch-sensitive screens instead of real switches and indicators, etc. Computer based displays can be configured so that they show the control panels of a cockpit including the changing positions of buttons and indicators. On top of the display is mounted a see-through touch-sensitive screen so that when the pilot slides a finger over the image of a button the button will then be set to the position in which the pilot leaves it. In this way, the design of the controls can easily be changed and the simulator can thus be used for many different types of aircraft. This gives far more training possibilities at the same cost, improving air safety. The question is whether users trained this way will be as skilled as those trained on the real controls. Risø is studying this in an EU-funded project, MATE – Multi-Aircraft Training Environment. Risø's results indicate not only that this type of simulator can be integrated with computer-guided instruction, but also that touchscreen-based controls can be an attractive alternative to real controls in part-task training simulators.

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First-aid efforts in major emergencies

An essential requirement for efficient emergency management is a facility for training both new and experienced personnel in emergency services. Within the framework of the EUREKA programme, Risø is developing a computerised training system that can easily be configured for different applications and situations. This system is being developed in collaboration with Danish hospitals. The prototype is designed for simulated on-site training of doctors with duties at three different levels: firstly the coordinating doctor responsible for acquiring knowledge of the number of casualties and the need for ambulances; secondly the doctor who prioritises the treatment of casualties; and finally, the treating doctor who gives first-aid, secures transportation of casualties and organises the distribution of casualties among the hospitals in the area.

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Energy systems analysis

Development of methods for analysing energy, environmental and economic conditions in relation to long-range energy-economy trends and the introduction of new energy technologies into complex energy systems.

The electricity markets and power pools

Denmark has a long tradition of trade and exchange of electricity with its Nordic neighbours. Danish legislation has not changed much over the past 10 years, while the other Nordic countries have restructured their electricity supply industries with removal of regional supply monopolies and the establishment of organised markets for electricity trade. A joint Norwegian-Swedish power pool, NordPool, was established in 1996, but also the Danish power companies participate in the trade. The export of power from Denmark has been much larger than the import, because it has been a dry year with low hydro power production. Risø participates in several research projects on opening up the European electricity and gas markets. A new project, carried out in cooperation with Roskilde University under EFP 96 will evaluate future Danish participation in a Nordic or Northern European power pool. It is particularly important to clarify the consequences for Danish power companies, especially concerning combined heat and power (CHP) and renewable energy, as well as the consequences for Danish energy and environmental policies. The development of a Northern European power pool may bring global environmental advantages, but it may also lead to substantial financial and organisational problems for power companies and governmental authorities.

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Forecasting energy consumption

In recent years, Risø has made substantial efforts towards the integration of macroeconomic and technical forecasting models. In 1996, work was finalised on the integrated model Hybris. Hybris integrates technical descriptions of the production and fuel choice of the energy supply sector – and technical descriptions of domestic electricity and heat consumption – into the macroeconomic ADAM model. The integrated model

Knud Garmann / Biofoto

Risø assesses the national economic gains at natural gas storage extensions. The picture shows gas storage facility at Stenlille, Zealand.

describes the interaction of the energy system, in particular the energy supply sector, and the macro-economy, and is suitable, for example, for calculating the effect of introducing a general CO_2 tax: a CO_2 tax would immediately reduce the demand for domestic electricity and heating – thereby reducing the capacity needed in the energy supply sector – and in the energy supply sector it would be relatively cheaper to use fuels that are light in CO_2. Fuel substitution has indirect effects on the electricity price. The combination of effects on private demand, fuel substitution in the energy supply sector and indirect price effects are special to the integrated models. The Hybris project was funded by the Danish Energy Research Programme. In a subsequent project, financed under the same programme, work is being done to integrate a very condensed version of Hybris' description of the energy supply sector into the official ADAM version. In 1996 the rebuilding of the INDUS model was initiated. INDUS is an integrated model forecasting the consumption of energy in Danish industrial, primary, construction and transport sectors. The project, which will be finalised by the summer of 1998, is funded by Danish Utilities and by the Danish Energy Agency.

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Costs of reducing greenhouse gas emissions in Denmark

The Danish Parliament has adopted a 20 % reduction of 1988 CO_2 emission-levels by 2005 and many reduction initiatives are either under consideration or have already been adopted. The associated costs are illustrated in the Danish energy plans, e.g. Energy 21, but these estimates are still very uncertain. Risø and DMU are therefore carrying out a project to assess the socio-economic costs involved. The primary objective is to assess the costs associated with initiatives to reduce greenhouse gas emissions from both the energy sector and a number of other sectors. For the energy sector, a general curve showing the costs of reductions has been set up based on initiatives introduced in Energy 21. In this connection, various other initiatives will be assessed for both the energy sector and other sectors such as transportation, industry, forestry and waste.

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National-economic benefits of natural gas storage

The overall national-economic gains achievable by extending underground storage capacity for natural gas in Denmark has been analysed in a project carried out by Risø and Rambøll. The project is supported by the Danish Energy Research Programme (EFP). The analysis includes an evaluation of gains achievable in light of seasonal load levelling during normal operation over the lifetime of storage facilities and gains related to strategic security of supply are discussed. Detailed optimisation of the gas storage operation in response to annual demand and price profiles in short time intervals is carried out in a number of scenarios. The consequences of size and time of commissioning of new gas storage facilities are analysed based on different assumptions concerning, for example, future demand for natural gas in different sectors of the Danish energy system, fuel price forecasts for natural gas and alternative fuels, as well as natural gas supply and grid extensions in Northern Europe.

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Energy planning in Egypt

For approximately three years, this joint venture between Risø and NREA – the New and Renewable Energy Authority – in Cairo, financed by Danida, has been working on a plan for wind energy in Egypt. The objective is to transfer knowledge, methods and models relating to planning in the wind energy field, asEgypt has excellent wind resources, e.g. along the west coast of the Red Sea. In the project, an organisation has been established to co-ordinate and analyse the elements in a long-term plan. Two Risø models were transferred and adapted to the Egyptian energy and statistical system, and local experts were trained in using the models. These are now being used to analyse wind energy in Egypt.

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Integrated energy, environmental and development planning

Development and implementation of integrated analysis methodologies for global, regional and national energy, environmental and development aspects and support for establishing national planning capacity, particularly in developing countries.

Land use and climate change mitigation

A Ph.D.-project at the UNEP Centre is contributing to the establishment of a framework to assess the potential for reducing climate change impacts associated with land use in developing countries. The methodology being worked out includes current national development needs as an integral part of the analysis and is being tested through case studies in Ecuador. Preliminary results show that the main emissions of GHGs take place when forests are converted into agricultural land. The project establishes baseline and reduction scenarios for the relevant sectors and evaluates the costs of identified mitigation options, as well as the broader social and environmental impacts using cost-effectiveness and multicriteria analyses.

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Power sector reforms in developing countries

As part of its support for UNEP's energy programme, the UNEP Centre has initiated a sub-programme to study the environmental and social implications of electric power sector restructuring in developing countries, focusing on Ghana and Thailand. The Centre is collaborating with the Ministry of Mines and Energy in Ghana to document the power sector reform process in Ghana with the aim of sharing that experience with other countries in the region. The UNEP Centre also participates in the work of a task force set up by the Ministry to examine regulatory and customer service issues for the power sector. Finally, the Centre is working on strengthening institutional interaction between the environmental protection agencies and the Regulatory Body to be set up. With Thailand, the UNEP Centre is preparing a study on how environmental considerations could be incorporated into electric power generation contracts by independent power producers.

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The UNEP Centre focuses on sustainable growth in developing countries

As part of their economic development in the coming years, developing countries will undertake a comprehensive expansion of their energy supply and consumption, and this can give rise to environmental impacts at national, regional and global levels. Major national impacts include local air pollution and acidification, while greenhouse gas emissions contribute to global climate change. Environmental protection may not be a main priority in countries where basic social and economic development needs have not yet been met. In many instances, developing countries need to give higher priority to investment in industrial development, infrastructure, energy supply, and general improvements in the standard of living of the population than to investments aimed only at improving the environment. This is particularly evident for investments whose sole significant benefits are long-term environmental improvements, such as mitigating climate change. A developing country may, therefore, experience little incentive in expanding its power supply system using relatively expensive, renewable energy sources. Instead it may be more inclined to utilise domestic coal resources, regardless of the environmental consequences. For this reason, viable development options should be both economically and technically attractive, and the general goal of welfare development linked to environmental considerations. An example of such an area of options is the development of more efficient – and at the same time more environmentally-friendly – land-use. Lack of fertilisers, irrigation systems and agricultural machinery can mean low productivity and depletion of soil nutrients. As well as leading to low agricultural production per unit area, this can lead to shifting cultivation and pressure on wooded areas. Thus inefficient land-use practices can lead to a reduction in the carbon bonding in trees, which is equivalent to increased carbon dioxide emissions. Such a 'vicious circle' can be broken through the adoption of more efficient agricultural production. In general, the energy and environmental problems of developing countries must be addressed locally, regionally and globally, while economic development is simultaneously strengthened. Consideration of such issues reflects the broadened scope of work at the UNEP Collaborating Centre on Energy and Environment at Risø, on the development of methodologies for integrated analysis of global, regional and national issues in the areas of energy, the environment and development. The Centre supports the enhancement of national planning capacity, particularly in developing counties.The UNEP Centre has already distinguished itself on the international scene, both in the development of analysis methodology and in the implementation of systematic model studies of economic and technical aspects of greenhouse gas reduction strategies in developing countries. The UNEP Centre has thus been assigned to develop what is expected to become the Climate Convention's international standard method of accounting for greenhouse gas reduction costs. One of the Centre's major projects in 1996 has been to lay the foundation for future international guidelines for how each country should report to the Climate Convention on the potential and cost of reducing greenhouse gas emissions. In the project, key financial concepts, models and analysis structures are set up, along with various technical assumptions. This establishes a framework for comparative assessments of the socio-economic consequences of implementing policies to reduce greenhouse gas emissions in the energy, transportation, land-use and waste treatment sectors. Developing countries that have ratified the United Nations Framework Convention on Climate Change are entitled to support from multilateral and bilateral sources in order to prepare their first national reports on emissions of greenhouse gases and potential reductions of these, as well as to establish the capacity to analyse national climate change mitigation issues in these countries. The UNEP Centre is providing such support to projects in 15 countries, covering at present: Argentina, Botswana, Ecuador, Egypt, Estonia, Hungary, Indonesia, Jordan, Mauritius, Peru, Senegal, Tanzania, Uruguay, Vietnam and Zambia. Local teams of government institutions, researchers and planners are conducting the studies following the methodological guidelines formulated by the UNEP Centre, and the Centre provides direct support, as well as formal and informal training, to the national teams. Internationally co-ordinated action among countries could help to reduce emissions of greenhouse gases in ways that are environmentally, economically and socially beneficial to the countries. In addition to the national level activities, the UNEP Centre is also involved in the investigation of regional collaboration among developing countries for the reduction of greenhouse gas emissions. Such collaboration could involve e.g. exploitation of joint hydropower resources or regional transport projects. The studies are focusing on Southern Africa and Latin America in collaboration with research institutes in the regions. The objective of the project is not only to support a regional basis for decision-making but also to point out areas where international support could be relevant. All these activities are carried out as part of UNEP projects financed by the Global Environmental Facility (GEF), Danida and the United Nations Development Programme (UNDP).

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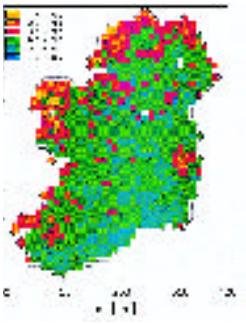
Anders Hejgaard / Polfoto

Developing countries that have ratified the United Nations Framework Convention on Climate Change are entitled to support from multi-lateral and bilateral sources in order to prepare their first national reports on emissions of greenhouse gases and potential reductions of these. The UNEP Centre is engaged in this project. The picture shows the Kariba dam in Zambia, one of the countries participating in the project.

Wind energy and atmospheric processes

Development of methods for designing, testing and siting wind turbines, determining wind loads and wind resources, as well as methods for determining dispersion, conversion and effects of air pollution.



With financial support from the EU Risø published the European Wind Atlas during the period 1980–90. The wind atlas provides detailed mapping of the European wind resources. From 1990 an improved method is developed at Risø and tested in Ireland.

Wind energy meteorology

Methodology and models for determining wind resources and the effects of wind on turbines and constructions in all types of terrain.

Wind atlas of Russia

Risø is making a first attempt to map the wind resources of Russia. The work is being carried out as a collaborative venture between Risø and the Russian-Danish Institute for Energy Efficiency (RDIEE) in Istra outside Moscow. To obtain the necessary information for this vast country, all available digital information must be used. The first very rough results show that high wind resources are typically found in the northern areas of Russia and also in some specific areas in other parts of the country. The atlas – to be published in Russian – is expected to be ready in mid-1997. The project is funded by the Danish Ministry of Environment and Energy.

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Wind resource prediction in complex terrain

The WAsP computer program for prediction of wind resources provides accurate predictions in terrain with gently rolling hills. This is based on the fact that the wind flow is attached in such terrain. Out of necessity, WAsP is also used for calculations in complex, mountainous terrain with steep slopes, which may result in both over- and under-prediction of the wind resources. In a study, Risø has, therefore, investigated the more precise cause and size of these discrepancies. The study is based on more than three years of wind measurements from six Portuguese stations with similar wind conditions but varying terrain steepness. The result is a correction scheme based on a 'ruggedness index', reflecting local conditions up to 3–4 km from the site. This allows reasonable account to be taken of the prediction error in WAsP. The work, which is supported by the EU JOULE programme, will be expanded using data from other complex terrain sites in Crete and Italy.

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Turbulence in complex terrain

Turbulence over flat, homogeneous terrain is quite well understood. Many wind turbines and other constructions are, however, situated on hilltops or in coastal areas where the character of the surface changes drastically. On the basis of models and experiments relating to the turbulence over idealised hills and simple changes of surface characteristics, Risø is developing a general model of the turbulence over an arbitrary terrain. The basic idea of the model is to calculate the modification of the turbulence due to the changes in the mean flow induced by the terrain. Despite the simplicity of the model, the results compare well with experiments. A preliminary version of the model is incorporated in Risø's WAsP model complex, while later versions will be incorporated in another of Risø's linear flow models, LINCOM.

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Successful prediction of wind farm power output

In areas with many wind turbines connected to the electricity grid, problems of sudden drops or increases in power production may occur. In addition, it is difficult actually to save fossil fuel without knowing the power production expected from wind energy, e.g. 36 hours in advance. Under the EFP programme, the Danish Ministry of Environment and Energy and has initiated a project, coordinated by Risø, whereby Risø, working together with partners from the Danish utility company ELKRAFT and the Danish Meteorological Institute (DMI), is implementing a model to forecast the power produced by the major wind farms on the islands of Zealand and Bornholm. The model was run operationally for a full year at DMI and a comparison of model calculations and actual power produced by the wind farms showed that the new model performed very well compared with models used today. The model is now being implemented in Denmark, the UK, Greece and the USA in an EU JOULE 3-funded project running 1996–99.

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Wind turbines

Methods of verifying the load and safety of wind turbines and analyses of their applications in the power system and hybrid energy systems for the purpose of development and exploitation of wind turbine technology.

Tools for feasibility studies

As a consequence of the major expansion in wind energy, the demand for accurate technical and economic assessments of wind farms is increasing. Risø is developing feasibility study methods and tools ranging from wind resource assessment (WAsP), wind farm array layout and energy production estimation (PARK), to power system analysis (WINSYS) and financial analysis. The development of these tools is an ongoing process which is very much governed by interaction with various clients and projects based on Risø's wind energy research and development worldwide. The following studies were completed in 1996: feasibility study in Cape Verde – three wind farms supplying 25% of power consumption in isolated power systems. Feasibility study of a wind farm in Syria. The assessment of an existing wind farm and a feasibility study of two proposed wind farms in the Czech Republic. The studies were financed by Danida, UNDP, the Danish Ministry of Environment and Energy, the EU APAS programme and others.

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Loads on wind turbines situated at sea

Wind turbines in wind farms affect each other, since turbulence from the rotor of one wind turbine can put an additional load on the next wind turbine. A large measuring programme at Vindeby Offshore Wind Farm's 11,450 kW Bonus wind turbines has increased understanding of what loading means for the risk of breakages due to fatigue in wind turbines. Two years of readings have given statistically reliable data that is unique in that there are no other disturbances close by, such as hills and houses. A model has been developed to calculate the significance of the effects, and this is expected to make wind turbines cheaper to construct.

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Strength requirements of wind turbines

A wind turbine rotor should be just strong enough to resist wind strength, but too much strength increases costs unnecessarily. It is, therefore, important to have precise methods for selecting

the right strength. Together with Det Norske Veritas, Risø has carried out a project to calculate fatigue strength of a rotor with airfoils of glass fibred plastic. In the calculations, so-called partial coefficients which have a direct bearing on the strength requirements are included. The project has determined these partial coefficients. The work has been partly financed by the EFP and the EU JOULE programme.

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International standardisation of wind turbines

Danish industry has made wind turbines an important export item for Denmark. Large exports can easily be hampered by 'technical hindrances to trade'. To help avoid such obstacles, Risø is an active participant in the development of internationally recognised standards in the area of wind turbines. Risø holds chairmanships of TC88, an International Electrotechnical Committee and a task force, BTTF83-2, under CENELEC. Risø also holds chairmanships of several task groups involved in designing the detailed standards. The work is supported and partially financed by the Danish Energy Agency.

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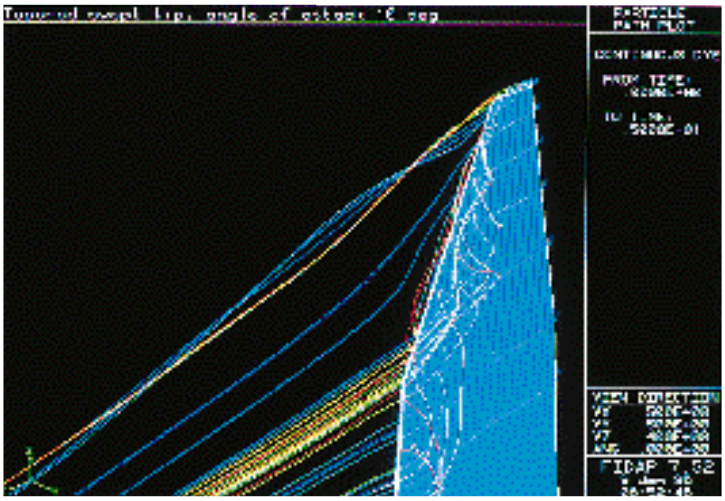
Aeroelastic design

Development of models for analysis of load basis, design and optimisation of wind turbines and new wind turbine concepts.

Rotor diameter and energy production

The change in wind turbine energy production obtained by using blade extenders has been investigated using a numerical computational fluid dynamic model developed in collaboration between the Technical University of Denmark and Risø. The necessary inputs for computation are the blade geometry, rotor radius and RPM of the wind turbine. Calculations corroborate measurements, showing that the increase in energy production was only half the amount expected from enlargement of the rotor area. This is due to the blade not operating under optimum conditions, in particular with respect to the three-dimensional flow characteristics, when fitted with blade extenders. The research was partly



New tip designs are partly based on three-dimensional CFD simulations of the flow field around the outer part of the blade.

Improved airfoils with reduced noise perform better

The world market is experiencing strong growth in the area of wind turbines, particularly since wind energy is regarded internationally as a potential cheap energy form for the future. The International Atomic Energy Agency (IAEA) and World Energy Council (WEC) estimate that in 10–15 years wind power will be one of the cheapest forms of energy. In its most conservative scenario, the WEC estimates that in 25 years there will be wind turbines installed all over the world with a total output of 180,000 MW. At the end of 1996 the total output from installed wind turbines was 6,200 MW. The anticipated development corresponds to a market potential of approximately DKK 1000 billion. Danish wind turbine companies and Danish technology are world leaders and the Danish wind turbine industry achieved a turnover of approximately DKK 4 billion in 1996. Wind turbines are now Denmark's fourth largest export item. One of the reasons for this success is that, for a number of years, there has been a comprehensive expansion of Danish expertise in wind power technology. This development has taken place as a result of joint efforts by the wind turbine industry, Risø, the Technical University of Denmark, the power companies and the Danish Energy Agency, which ensure a good basis for the future in industry and research. One of the major goals of Risø's wind energy research is to improve energy effectiveness and economy in wind turbines through combined research and development efforts in a series of specialist areas, from aerodynamics to materials technology. In practice, it has been a question of the development of lightweight, energy-efficient, low-noise wind turbine blades of 25–30 m, corresponding to a wind turbine output of 1–2 MW. The objective is clearly formulated in Risø's contract with the Ministry of Research and Information Technology: at least 10% improvement in energy effectiveness, and the establishment of collaboration with Danish wind turbine manufacturers on the implementation of new advances within the contract period. The objective is well within range as a result of using a recently developed optimisation tool. Following several detailed optimisation measures for a 1 MW rotor, the design parameters with the highest potential for reduction of the production price have been mapped. The extreme loads on wind turbines have proved decisive. If these could be totally ignored, the production price would be directly reduced by approximately 11%. Other design parameters with significant potential for reducing the cost of production (5–6%) are new profiles with optimised properties and improved materials (1–2%). In the next year, work will focus on the most promising design parameters in order to clarify what can actually be achieved in the way of improvements. The research is partly financed by the Danish Energy Agency.

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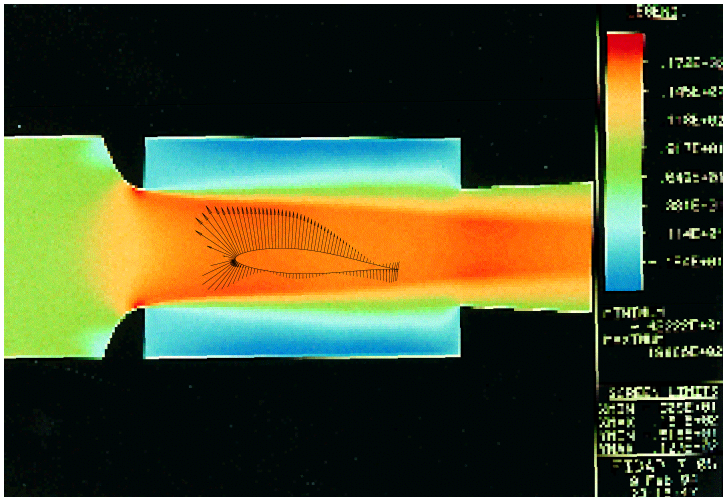

Measurement of the surface pressure distribution on new airfoils is an important step in the design phase in order to verify the target airfoil characteristics. A section of the airfoil with around 60 holes distributed on the surface is mounted in the wind tunnel and with pressure scanner equipment the surface pressure can now be measured.

financed by the Danish Energy Agency.

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Stability of wind turbines under stalled conditions

The stability of wind turbine blades under stalled conditions has been investigated. The stability phenomena are controlled by a wide range of parameters and the research concentrates on identification of the main parameters by means of measurements and aeroelastic simulations. Several parameters have been identified. An example of an important parameter is the orientation of the principal bending axes along the blade, which determines the relevant form of the blade under stalled conditions. The research is partly financed by the Danish Energy Agency and EU JOULE programme.

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Wind tunnel testing of airfoils

A procedure for wind tunnel testing of airfoil sections has been developed for both static and dynamic conditions. Pressure measurements on the airfoil and in the airfoil wake together with other measurements reveal the aerodynamic properties of the airfoil. The aim is to develop the necessary tools for testing new airfoils for wind turbines, including model manufacturing, wind tunnel testing and interpretation of results. So far, the so-called NACA 63215 airfoil and a new 13 % airfoil, Risø-1, developed at Risø, have been tested. A good correlation with calculations and other experimental investigations was found. The Risø-1 airfoil shows very promising stall characteristics and the measurements may, among other things, be used in developing dynamic stall models. The project is partly financed by the Danish Energy Agency.

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Electrical design and control

Analysis and development of new methods of control, electrical machinery, power electronics and dimensioning of the interaction of wind turbines with power systems.

Power control for wind turbines

In a project funded by the EU and co-ordinated by Risø, a new power control concept for wind turbines is being developed. This will make it easier to connect wind turbines to weaker grids. The principle is an AC/DC converter combined with battery storage. The AC/DC converter can either be an 'add-on' type or it can be an integral part of a variable rotor speed wind turbine. The cost of the power control should be recouped as more wind turbines can be connected to the grid, while, at the same time, grid reinforcement costs can be saved. The project comprises development, prototype testing and case studies. To gain actual experience, ABB (Norway) has developed a 50 kW, 30 kWh add-on control system that is now installed for testing purposes on a wind turbine at Risø. Case studies are being conducted for Madeira and County Donegal in Ireland. Both areas have favourable wind conditions and limited grid capacity for large-scale utilisation of wind power.

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Atmospheric transport and exchange

Studies of atmospheric transport and of airborne particles and their exchange with synthetic and natural terrestrial and aquatic ecosystems.

Particle exchange between atmosphere, plants and soil

Measuring the exchange of particles between the atmosphere and terrestrial and aquatic ecosystems is a dynamic process that requires fast measuring methodology which also takes account of air turbulence. The results lead to a deeper understanding of some fundamental mechanisms in the spread and transport of pollution in the ecosystems. Risø participates in this research not only in studies of the processes, but also in evaluating the impact of flux on the ecosystems for a range of different substances. Flux is understood as the transport of particles per unit of area and time. For many particles, the magnitude of these fluxes is still not known, even though they are of key importance in assessing a range of important environmental questions. The following five projects are examples of Risø's comprehensive research in this area.

Satellites provide data for calculating surface fluxes

Climate and transport models are difficult to set up, because the resolution of such models is typically no better than 100 km, due to the limitations of current computer capacity. Variability in the landscape and, therefore, the small-scale surface conditions must be aggregated in the model. Risø's contribution to this research is the development, testing and validation of a microscale aggregation mode, based on the use of Fourier calculations to handle real terrain data. The model has been tested, with convincing results, using data from various experiments and satellite-derived data, as well as measurements carried out in the Rhine Valley in Germany. Data from a large-scale experiment in Canada (BOREAS) will be used to validate the model in relation to the calculated spatial flux.

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International biosphere-atmosphere exchange experiment

In 1996, an 80-year-old beech forest near Sorø provided the trees and soil for experiments on the exchange of nitrogen oxides and ozone between forest and atmosphere. In the forest, a 57 m high meteorological mast and a 24 m high tower were erected with equipment for the experiment. This installation is part of the EUROFLUX project mentioned above. Nitrogen oxides acidify and act as a fertiliser. Volatile organic compounds (VOCs) and nitric oxides are part of the photochemical atmospheric pollution leading, among other things, to ozone formation. This atmospheric pollution affects wildlife and causes serious loss of yield in agriculture. It is possible to restrict this ozone pollution by countering the nitric oxides. In the experiment, besides the biogenic emission of nitric oxide from the soil, fluxes were ascertained at several heights above and below the canopy. Preliminary results show that, under some circumstances, the forest acts as a source of atmospheric nitric oxides and, under other circumstances, the forest compounds nitric oxides. The experiment was financed by the EU and involved partners from TNO (The Netherlands) and the University of Manchester (UK).

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Exchange of particles between atmosphere and sea

The air-sea flux of CO_2 has been studied in a number of EU-funded projects. The OMEX project has determined the atmosphere-ocean exchange. Exchange processes in the North Sea have been studied in the ASGAMAGE project. Wind-water tunnel studies were simultaneously conducted in the LUMINY project to determine more closely the detailed processes governing part of the exchange. A significant result from the OMEX experiment in 1996 has been obtaining the first consistent fluxes from ship measurements by using micrometeorological and biogeochemical techniques. The water soluble gaseous pollutants, HNO_3 and NH_3 are important for ocean nutrient budgets, especially for coastal seas. Measurements obtained at the Vindeby Wind Farm site and at a little island west of Gotland have produced a wealth of new information about the water-air exchange of these gases. The work has been conducted as an international collaborative venture, with funding and science partners coming from a wide range of institutions and countries. Risø and DMU are the main Danish partners.

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Water vapour and CO_2 fluxes between atmosphere and forest

Risø has long been involved in meteorological measurements in a forest site in Ulfborg and this project has been reinforced on two counts. A so-called sonic anemometer allows more detailed measurements of wind speed and new software supplies data for the flux calculations. Another new development is closer collaboration with teams of researchers observing the phenological variations at the forest plot. Expressed simply, phenology is the study of the adjustment of living organisms to seasonal and climatic changes in the environment they inhabit. The goal is to correlate this knowledge with extreme meteorological events such as drought and early or late frost. Risø is to determine the carbon and water budget of the ecosystem in a beech forest at Sorø. Continuous flux measurements of CO_2 and water vapour are being carried out using the Eddy-flux method, based on calculating the flux of a chemical compound through a horizontal plane as the product of an instantaneous concentration and the vertical wind velocity. The Project (EUROFLUX) is funded by the EU, initially for three years, and is part of a worldwide flux network within the International Geosphere Biosphere Programme.

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Flux and chemical scalars

The above experiment at Sorø has also been used to set up a theory for flux and the concentration of passive scalars. In atmospheric physics, a 'scalar' is a physical quantity that can be described as a single function of time and space. In contrast to this there are, for example, wind speeds that are generally vectors, i.e. three functions (one for each velocity component), which are all functions of time and space. Scalars may be temperature, moisture, gases (e.g. carbon dioxide) or aerosols. As a rule, 'chemically active scalars' are perceived as gases that may react chemically or photochemically with other gases in the atmosphere in such a way that at a given time and place, they can form and disappear without wind transport. Knowledge of chemically active scalars in the atmospheric boundary layer are important in environmental planning. The experiments have led to a theory on chemically active scalars being proposed. The theory predicts in detail how the flux and concentration decrease with height in the so-called constant-flux layer.

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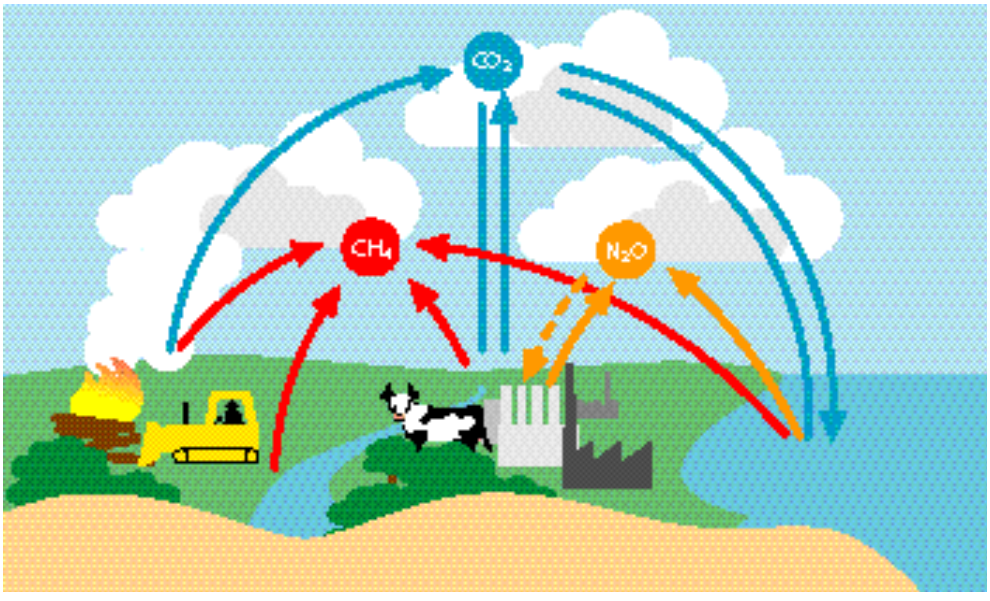

Sources to and fluxes of various greenhouse gases. The sources are natural as well as man made.

Radioactive clouds do not respect national boundaries

Risø is co-ordinating the development and implementation of an atmospheric dispersion module named MET-RODOS, part of the joint European real-time decision support system RODOS. The purpose of the system is to provide early warning and real-time decision support in connection with any future nuclear accident. The aim is for the RODOS system to be fully operational by the year 1999. The project, involving partners from Central and Eastern Europe as well as most of the EU countries, is a joint research project within the fourth EU Radiation Protection framework. The MET-RODOS module can calculate atmospheric dispersion, making it possible to forecast radioactive airborne spread on a local, national and European scale. The MET-RODOS module has on-line connections to local meteorological stations and Internet or ISDN network connections to national and international meteorological institutions. Risø's LINCOM package for the calculation of wind conditions over hilly terrain is also included in the MET-RODOS module. Based upon a small number of wind measurements it gives the detailed wind fields over the area of interest, i.e. around the failing nuclear facility. These fields are then used by the RIMPUFF dispersion program for the calculation of the spread of the radioactive clouds. In 1996 the LINCOM model has been extended to include the effect of non-homogeneous surface roughness. This gives a more accurate prediction of the time of arrival of radioactive clouds at a particular area when, for instance, a land/water/land surface is traversed, and the calculation of deposition of radioactive material to the ground is potentially enhanced.

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Atmospheric chemistry

Determination of the mutual importance of various substances and processes for the purpose of indicating precautions and alternatives to reduce the effects of airborne pollution.

More knowledge of freon alternatives

Scientifically, the problem of halogen in the stratosphere has now been solved. With the international ban on CFCs that has been introduced and the replacement products that will come into use, it has been calculated that ozone depletion will reach its peak around 1999, and by the middle of the next century, the ozone layer should be almost repaired to the level of the 1970s. On the other hand, there may be a problem with one of the breakdown products from the most frequently used alternative, HFC-134a. In reactions in the atmosphere, it appears as though some of the breakdown products produce the compound trifluoracetic acid. It is not known exactly how this affects humans and crops, and unfortunately it cannot be broken down. Work is therefore being done to establish what quantities of the compound are being formed. In collaboration with Ford Motor Company, Risø has identified a new and more realistic process in the laboratory. This demonstrates that there should be two to four times less trifluoracetic acid being formed than has been assumed until now.

Ole John Nielsen
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The chemistry of nitrogen oxides in the atmosphere

Nitrogen oxide emissions from cars, industry and power plants result in 'acid rain' and the formation of poisonous air pollutant components. The nitrogen compound HONO is one of the most important air pollutants that can only now be measured correctly thanks to a new method developed at Risø. In collaboration with eight other European research laboratories, Risø is now participating in the EU FORMONA research project to determine reliable UV absorption cross-sections for HONO use in field measurements of HONO in the atmosphere.

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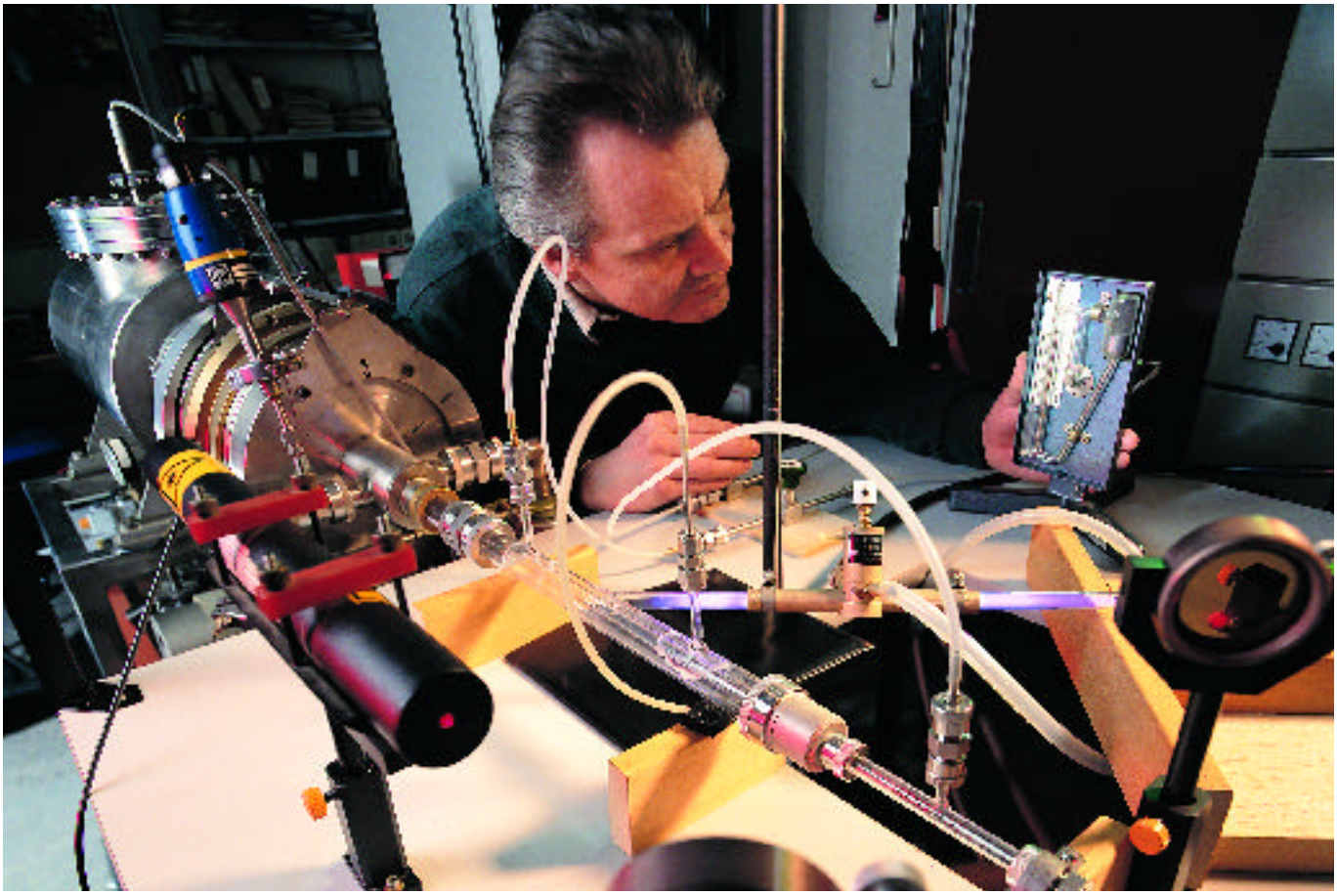
Søren Jensen / Polfoto

Alternative CFCs in automotive air conditioning units will help the recovery of the ozone layer.



Investigations of dimethyl ether with discharge-fast-flow technique.

Tar problems with bio-fuels

Gasification of bio-fuels constitutes an attractive and promising prospect for the exploitation of bio-fuels at heating and power stations. It is now being sought to apply this method on a large scale at the heating and power station at Harboøre. A significant factor for smooth operation is low content of tar products in pyrolysis gases. In collaboration with the Technical University of Denmark, Risø is seeking to establish the optimum operating conditions for the process. A by-product of the process is waste water with high tar content. In collaboration with the Technical University of Denmark, Risø is examining the prospects of a profitable solution, including channelling the tar fraction back into the gasification process or using controlled detoxification. The research is supported by the EFP.

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Manganese prevents harmful ozone formation

Transition metal ions (TMI), especially iron and manganese, are present in rain, cloud water and fog. So far, the effect of TMI on ozone formation in the troposphere has been investigated only in terms of sulphur dioxide and nitrogen oxides. In the troposphere, ozone functions as a greenhouse gas, as well as a cause of serious crop damage. Risø has investigated the formation of a manganese-oxygen complex, MnO_2, and manganese acting as a catalyst in the destruction of ozone in the troposphere. The results support the hypothesis that TMI and especially manganese reduce the oxidation capacity of the troposphere when manganese, ozone and hydrogen peroxide are simultaneously present. This corroborates the fact that no increase in tropospheric ozone has been detected in areas where organic manganese compounds are used instead of tetraethyl-lead as an anti-knock additive in petrol.

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Customised alternative fuels

Risø is contributing to the development of new fuels and fuel additives characterised by their oxygen content. Risø is carrying out detailed studies of the processes of combustion chemistry at the molecular level. These studies include measurements of both open flames and selected elementary reactions. Studies of a range of potential compounds have already shown the potential for tailoring and customising alternative fuel types. The research is supported by the STVF.

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Nuclear safety

The development of methods for radiation protection and assessing reactor safety for the purpose of determining and limiting radiation doses and providing a basis for consultancy on nuclear issues.

Radioecology

Determination of the transfer of radioactive substances in the environment and assessments of radiation doses to man, developments of methods to reduce levels of radioactive contamination in urban areas and the subsequent doses to man.

Evaluation of early phase nuclear accident clean-up procedures

Over the latest decade, a large amount of information has been obtained at Risø on the behaviour and possible removal of radionuclides deposited in inhabited environments. This information, together with Monte Carlo calculations of radiation transport, has been used to form a catalogue of descriptions of feasible remedial countermeasures. These countermeasures are to be implemented in the early phase to reduce the external radiation dose in the event of a major accidental contamination of inhabited areas in the Nordic countries. The catalogue, which is to be used in the Nordic preparedness, comprises estimates of the dose reductive effect obtained by application of each feasible countermeasure in different contamination scenarios, representing varying population densities and weather conditions. Likewise, the costs of application of the procedure under the specified conditions have been stated, including the required manpower, consumables, overheads, etc. The formation of the catalogue was supported by NKS.

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They look good but they are not meant for eating. They are part of a project at Risø that monitors the radioactive pollution of Danish food.

Radioactive pollution at Mururoa and Fangataufa

Risø participates in the international investigation of the radioactive contamination of the marine environment at Mururoa and Fangataufa in French Polynesia following the cessation of nuclear weapons tests. French results indicate that the surface tests of 1966–67 in particular have left radioactive contamination in the environment. In July 1996 Risø participated in the international group taking samples from the marine environment, and Risø is now one of the seven international laboratories carrying out the analytical work. The measurements include plutonium isotopes, americium-241, strontium-90, caesium-137 and europium-155. A final report on the findings is planned for the spring of 1998. The work is carried out under the auspices of the International Atomic Energy Agency (IAEA).

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Decontamination of Novo Bobovichi

Even 10 years since contamination by the Chernobyl accident, external radiation levels in several Russian settlements still exceed acceptable limits. In some cases, the situation has recently worsened as people have moved into previously evacuated areas as a result of war and civil unrest. To date decontamination in the former Soviet Union, has achieved a reduction in external dose of only 10–50 % and this is not sufficient. From experimental decontamination tests carried out by Risø, we showed that it should be possible to reduce the external dose by a factor of three or more. We therefore welcomed the challenge when the Emergency Management Agency supported a project where the Risø approach could be tested in a realistic scale in the Russian settlement of Novo Bobovichi. The results of the work confirmed Risø's prediction in that a mean dose-reduction of greater than a factor of three was achieved. Although buildings presented special problems a high pressure KEW washer with turbo nozzle and a specially built Danish developed roof cleaner achieved worthwhile reductions in contamination levels. The study showed conclusively that even 10 years after the initial contaminating event, a very significant reduction in external radiation levels can be achieved.

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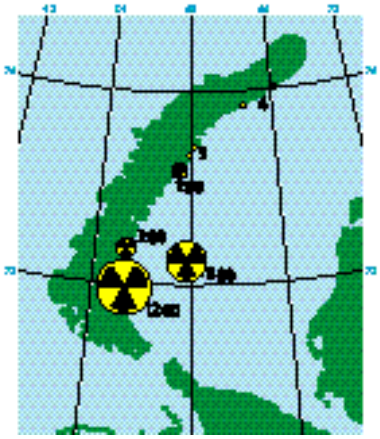

Map showing the locations in the Kara Sea where dumping of radioactive waste have occurred. The size of the symbols and the numbers indicate the amount of radioactivity (kilocuries) at the time of dumping.

Low risk from atomic waste in the Arctic Ocean

In 1996, Risø has participated in an international study organised by the IAEA on a radiological assessment covering the marine environment in the Arctic Ocean, where the former Soviet Union has dumped large amounts of nuclear waste. The results of the assessment show that the potential risks from this waste are small and that countermeasures are hardly needed. Radioactive contamination from the dumped waste in fish caught in the Greenland and Norwegian Seas will be insignificant.

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Radioanalytical chemistry

Development and application of radiochemical methods of analysis to determine elements that are important to health and to the environment.

Radioanalytical chemistry

The Isotope Laboratory participated in an intercomparison arranged by the National Institute for Occupational Health prior to participation in an EU project concerning the preparation and certification of human serum and urine. As, Se and Zn were determined by NAA. Cooperation with the John F. Kennedy Institute has continued with the diagnosis and verification of Menkes disease by the determination of Cu in chorioni villi and placenta samples by radiochemical NAA. In cooperation also with the University of Helsinki, As, Cu, Mn and Se were determined by radiochemical NAA in samples from patients with

occipital horn syndrome. A project for determining Pt in various organs of cancer patients was completed. An improved method was developed for the determination of trace amounts of Pt in airborne dust and soil from Copenhagen. In cooperation with Ben Gurion University in Israel, we attempted to determine Pt in highly polluted air filter samples by instrumental neutron activation analysis.

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Reactor safety

Development of the necessary expertise in reactor safety through a combination of knowledge-gathering and research in selected areas.

Report on the international status of nuclear power

In March 1996 the second report on the international status of nuclear power was published (in Danish). The report was prepared as part of the work of the Danish Nuclear Knowledge Preparedness programme (DNKP). The purpose of DNKP is to ensure that sufficient knowledge exists in Denmark in the nuclear field to provide the necessary consultancy to Danish government authorities and others. DNKP is a joint venture involving Risø, the Technical University of Denmark and the Emergency Management Agency.

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Preparedness against a serious accident at a nuclear power plant

In case of a severe accident at a nuclear power plant, a large part of the fission products released from the damaged reactor core will be deposited as particles in the primary system. Under certain conditions, these particles may become detached and therefore be released into the containment atmosphere; they may become resuspended. The aim of the STORM project is to study this resuspension. The experiments are performed at the EU Joint Research Centre in Italy. In the same field, Risø's research has been extended to include core meltdown and cooling of a molten core within the reactor vessel in a light-water reactor. A literature study has been conducted based on a series of international reports as part of the work of Nordic Nuclear Safety Research (NKS).

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Potential risks of nuclear submarines

As part of NATO/CCMS/NACC studies on cross-border environmental problems emanating from military installations and activities, three investigations have been carried out. The potential sources of cross-border radioactive pollution due to naval activity have been evaluated. The risks of reactivity accidents in decommissioning nuclear-powered submarines have been studied, and a simple model for such accidents has been developed. A report has been prepared on accidents involving nuclear vessels.

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Data for nuclear power plants

The Nordic Nuclear Safety Research (NKS) programme includes information on nuclear power plants situated outside but close to the Nordic countries. The purpose is to provide the necessary information to be able to evaluate the consequences of an accident at one of these nuclear power plants. In 1996 information has been collected on nuclear power plants in the UK, and Risø has been responsible for the collection of data for the Advanced Gas Cooled type of Reactors (AGR) plants.

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Radioactivity of reactor components

In the context of radiation damage, repair work and, ultimately, decom-

Nordfoto

Russian Yankee-class nuclear submarine which has been decommissioned and which is to be disposed of together with about 100 Russian nuclear submarines, partly due to international disarmament agreements, partly because the submarines are worn-out. Risø has studied the risk of reactivity accidents during decommissioning of nuclear submarines as part of an international cooperation project.

missioning work, it is important to know the radioactivity of internal components of the reactor tank as well as that of adjacent external components. Risø has developed computer programs suitable for making such evaluations. Calculations have been performed for Swedish power stations on several occasions, e.g. calculations of neutron doses and activities of the moderator tank at Ringhals 1 and of the pressure vessel at Forsmark 1.

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Radiation Protection

Development of the basis for effective protection against harmful effects from natural and man-made radiation sources.

Improved early warning of nuclear accidents in the Baltic States

Risø has tested and calibrated prototypes of the measuring stations which the Danish Emergency Management Agency (BRS) has donated to the Baltic countries and to Poland. The stations, which are produced by Greenwood Electronics A/S and Prolog Development Center A/S, can distinguish between the natural background and a dose-rate contribution from radioactive contamination in the event of a nuclear accident. On behalf of the BRS, Risø has inspected the proposed sites prior to installation of the measuring stations.

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Consequences for Denmark of an accident at the Ignalina power plant

A stochastic model for long-range atmospheric transport has been developed and has been applied in a probabilistic assessment of the radiological consequences for Denmark following a hypothetical serious reactor accident at the Ignalina Nuclear Power Plant in Lithuania. Assessing the consequences after a nuclear accident requires mathematical modelling of the atmospheric transport of the released activity. Transport models may be deterministic for the use in nuclear emergency response programmes, using real-time meteorological information. Alternatively, they may be probabilistic, as in this study, in order to assess the consequences of hypothetical future emissions. The deterministic atmospheric transport model used by the Danish nuclear emergency authorities will now be incorporated into Risø's work to prepare prognoses in case a nuclear emergency should arise either within or close to Danish territory.

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Beta spectroscopy in skin dosimetry

As part of a three-year EU project, Risø is studying the use of beta spectroscopy for dosimetry applications. Information on the beta spectrum of mixed beta/gamma radiation fields is crucial for the determination of skin doses as well as for identification of the radiation sources in question. In addition, this information is valuable when decisions on the necessary radiation protection have to be made. Beta spectroscopy is, therefore, well suited for area monitoring of workplaces and accident areas. A spectrometer using three silicon detectors is under construction. This spectrometer will make it possible to measure beta spectra in mixed beta/gamma radiation fields.

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Risø's calibration field, where new measuring stations for the East European nuclear early warning systems have been calibrated.

Radon levels in houses can be decreased

Radon gas seeps into our homes from the underlying soil. Radon is a decay product of uranium which is present in all soil types, mostly in granite areas such as Bornholm and least in sandy soils such as in Western Jutland. Risø and The National Institute of Radiation Hygiene (SIS) has earlier demonstrated that approximately 40,000 detached houses in Denmark have an indoor radon concentration above 200 Bq/m³ (becquerels per cubic meter). As an estimate radon causes 300 lung cancer deaths per year in Denmark. A maximum permissible indoor radon levels has not yet been adopted. However, SIS points to a possible action level of 200 Bq/m³. Risø has carried out an investigation of radon mitigation methods. The investigation, which was completed in 1996, included radon measurements in three areas in Denmark where high indoor levels of radon could be expected. The areas studied are Thisted, Ramsø and Bornholm. In Thisted and Ramsø, radon levels of up to 370 Bq/m³ were recorded, while levels on the island of Bornholm were as high as 1000 Bq/m³. Risø's mitigation attempts show that it is possible to reduce the radon levels considerably. Sub-slab depressurisation using mechanical air extraction in the capillary breaking layer proved to be a very efficient method of reducing indoor radon concentrations. Similarly, active ventilation of underfloor crawl space or basement rooms also had a positive effect. Passive mitigation techniques were also tested. These methods included an attempt to seal the concrete slab of a house by means of foil covering, a passive ventilation system and improvements of existing passive ventilation systems. These passive mitigation measures proved to be less effective than the active ones. The project was financed by the National Building and Housing Agency and SIS, and was carried out in collaboration with SIS, SBI, GEUS, and COWI.

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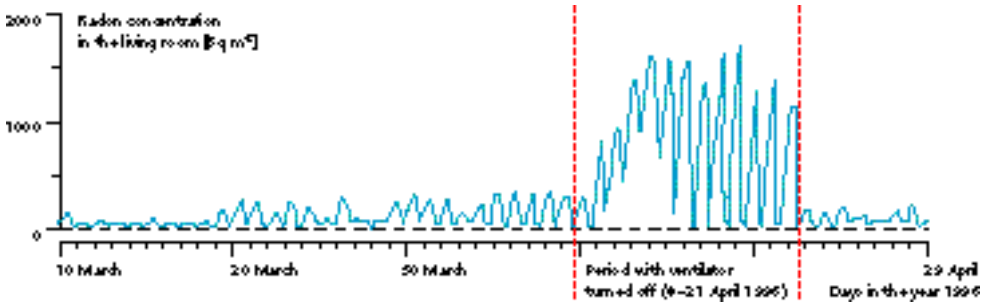
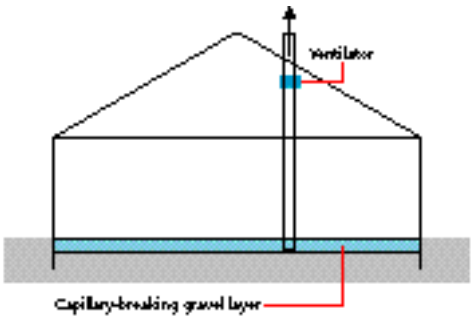




The dominant source of radon in Danish houses is entry of radon-laden soil gas through cracks in the concrete slab of the house. This entry is mainly caused by small indoor-outdoor pressure differences, that result from heating of the house (the chimney effect) and wind acting on the house. An efficient method to prevent radon entry is to outbalance these small natural pressure differences by installation of a so-called sub-slab depressurization system: A fan is located in the attic and through one or more ventilation channels, air is sucked from the capillary-breaking gravel layer below the house. This creates a relatively large underpressure, so that the pressure difference across the concrete slab is reversed. Now the air flows from the house interior to the ground – not in the opposite direction. This prevents entry of radon to the house. The top figure shows results from an experimental test carried out in a Danish house where such a system had been installed by Risø in collaboration with a number of other Danish institutions. The sub-slab suction was on for the entire period shown in the figure except for the part highlighted in red. It is seen, that the radon concentration in the house increased markedly when the system was switched off, and that it decreased again when the fan was turned back on. Over a full year, the system has decreased the average radon concentration of the house from 1000 Bq/m³ to 50 Bq/m³. The average radon level of Danish single-family houses is about 70 Bq/m³.

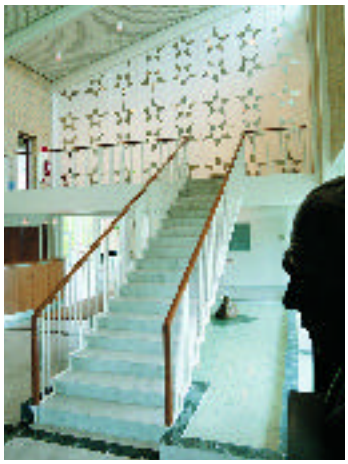
Research departments

Materials Research Department
The department develops and studies materials and materials technologies to find economically feasible and safe applications for advanced materials. Activities cover long-range research, design and testing, and are particularly directed towards the energy and industrial sectors both in Denmark and internationally. The key areas of expertise in the department are materials physics, solid state mechanics, electro-chemistry, materials technology and mechanical design and testing, as well as interdisciplinary combinations of these areas.

Condensed Matter Physics and Chemistry Department
(Formerly the Department of Solid State Physics) The research of the department focuses on the synthesis and structural characterisation of materials, including new polymers, at the atomic, molecular and supramolecular levels. A significant part of the research utilises neutron radiation from Risø's DR3 research reactor and X-radiation from the synchrotron facilities in Hamburg and Grenoble. In this connection, work is carried out on developing advanced methods, as well as theory and computer simulation. The key areas of expertise in the department are condensed matter physics, structural chemistry, chemical synthesis, and interdisciplinary combinations of these areas.

Optics and Fluid Dynamics Department
The research of the department aims in particular to understand nonlinear processes in optical and fluid dynamic systems as well as the development of diagnostics methodology and information processing that can be applied in research and industry. The foundation is laid for new types of miniaturised optical systems, including systems for image and pattern generation. Key areas of expertise in the department are physical optics, continuum dynamics, mathematical-numerical methods and information processing.

Plant Biology and Biogeochemistry Department
(Formerly the Department of Environmental Science and Technology) The research of the department is primarily directed towards the need for cost-effective plant production with minimal adverse impact on the environment. Besides this, the research helps to alleviate and restrict adverse impact on the environment resulting from energy consumption and industrial production. Key areas of expertise in the department and opportunities for experimentation include genetics and genetic engineering, chemical kinetics, ultra-



Risø's auditoriums were rebuilt in 1996. The new decoration was created by the artist Viera Collaro.

sensitive analyses of trace elements, as well as controlled multi-parameter experiments in RERAF.

Systems Analysis Department
The objective of the research is to develop and apply methods and models to provide Danish society and international organisations with an improved basis for decision-making concerning technological priorities in society. Key areas of expertise in the department are systems reliability, organisation, toxicology, informatics, simulation methods, work studies, economics and experimental psychology. The UNEP Collaborating Centre for Energy and the Environment in Developing Countries is also part of this department.

Wind Energy and Atmospheric Physics Department
(Formerly the Department for Meteorology and Wind Energy) The research of the department aims to meet the need for knowledge and consultancy on wind turbines and the exploitation of wind power, as well as to map and alleviate atmospheric pollution in collaboration with DMU (the National Environmental Research Institute). The key areas of expertise in the department are boundary layer meteorology, aerodynamics, aero-acoustics, and machine and construction technology exploiting full-scale field tests, laboratory tests and advanced numerical simulation.

Nuclear Safety Research and Facilities Department
The department carries out research and development in the areas of nuclear safety and radiation protection in order to provide competent consultancy to the government authorities and others. Key areas of expertise in the department include reactor physics, radioecology, radiation measurement, dosimetry, and dispersion and dose calculation. Facilities included within this department are the DR3 research reactor, the DR1 training reactor, the Radioactive Waste Processing Laboratory and the Isotope Laboratory, which is developing radio-chemical referencing methods for environmental applications.

Staff functions

Management Secretariat
The Management Secretariat supports Risø's management.

Head of Press Relations
The Head of Press Relations takes care of Risø's relations with the press and electronic media.

Personnel Office
The personnel office has responsibility for personnel policy development, employee development and dealing with personnel matters.

Technical and administrative departments

Building and Construction Service Department
This department is responsible for running and maintaining buildings, installations, supplies and grounds as well as transportation and all building facilities work.

Engineering and Computer Department
The department develops, produces and maintains electronic and mechanical equipment for experiments. The department is responsible for operating and maintaining Risø's central computing equipment and data networks. A key activity in 1996 has been the develop-

ment and construction of a new horizontal radiation facility for irradiation of silicon in the DR3 research reactor. The new facility is intended to increase the capacity and improve the quality of the process. Another activity has been the development of electronic equipment for measuring wind, waves and currents in connection with a field study on optimising wind farms situated at sea.

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Information Service Department

The department is responsible for external and internal information, the library services, filing and records management, as well as Risø's design programme and graphic services. Risø's external web-service has been expanded with access to the full text of a number of key publications such as Risø's Annual Reports and 'Risø's Strategy'. In 1996 the first steps were taken towards an intranet service which will allow Risø employees to have full access to all the information needed at Risø day by day. The first version includes, notably, simplified access to some key databases and electronic editions of the internal staff newsletter, etc. In the course of 1996, a number of assignments were completed for external users; the largest single task falls under the EFP programme incorporating the communication of Danish energy research in the form of information to international databases on Danish energy literature and Danish energy research projects. See also the sections on 'Information' and 'Risø Library' in the chapter 'Dissemination of knowledge and research results'.

Birgit Pedersen
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Safety Department

The department supervises and advises on safety at Risø. The department covers the areas of health (BST), the working environment, the external environment, fire, security and registration of fissile material in Denmark, as well as monitoring radiation and pollution levels at nuclear installations.

Economy Department

The department takes care of functions relating to finance, project administration, purchasing and the Instrument Team of the Research Councils (FRIT).

Experimental facilities

Risø's large experimental facilities ensure opportunities to carry out experimental research of international calibre, affording Risø a special role as a research centre offering facilities to external users.

RERAF.

Research reactor DR3

The DR3 research reactor produces neutrons for use in materials research and the commercial production of isotopes for industrial and medical applications. DR3 is Denmark's contribution to the international network of 'Megascience' facilities, and Risø receives EU support to promote use of DR3 by European researchers. The reactor has performed as planned in 1996, having been in operation for more than 6,500 hours, corresponding to 75 % of the year. In the course of a six-week maintenance period, the reactor proved to be in good order.

Heinz Floto
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RERAF

In the RERAF greenhouse facility, Risø's Environmental Risk Assessment Facility, multi-parameter experiments are carried out in areas such as the interaction between plants and micro-organisms, the development of new plant properties by means of transformation, as well as assessment of risks from spreading genes. The first section of RERAF has been operational since the autumn of 1996 and the installation is now being commissioned.

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Electron accelerator

The electron accelerator is used in studies of radiation-induced reactions significant to atmospheric chemistry, industrial irradiation and dosimetry.

Isotope Laboratory

The Isotope Laboratory produces radioactive isotopes and other radioactive materials for industry, hospitals and research institutions. Most deliveries to Danish and international customers are unprocessed irradiations, while all radioactive samples for Risø's own research are supplied as ready-to-use preparations. For the electronics industry, the Isotope Laboratory performs commercial irradiation of silicon for semiconductor components. A new horizontal facility is scheduled for installation in 1997. In 1996 new trolleys for the transportation of silicon irradiation cans were developed. The Isotope Laboratory's own research is focused on the development of reference methods in radioanalytical chemistry. In 1996, the laboratory was involved in the determination of trace elements in vegetables using instrumental neutron activation analysis. These analyses are considered to be a quality control of conventional analytical methods and are part of the FØTEK2 programme.

K. Heydorn
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Waste Management Plant

Radioactive waste products from the nuclear research facilities at Risø and from other Danish users of radioactive materials are collected, processed and stored at the Waste Management Plant at Risø. Characterisation and transfer of the old waste units to a new storage facility was finalised recently. Staff from the Waste Management Plant parti-

cipate in international research and review studies of various aspects of the safe disposal of radioactive waste.

Knud Brodersen
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Special units

Test Station for Wind Turbines
Risø operates the Test Station for Wind Turbines with funding from the Danish Energy Agency. The purpose of the station is to promote the use of wind power in Denmark and abroad through the testing, approval and certification of wind turbines.

Risø Visitor Centre
The centre arranges visits by appointment for groups from industry, societies, organisations and educational institutions, including the 8th–10th grades of school. See also description under the section 'Dissemination of knowledge and research results'.

Risø Library
Risø Library is open to the public. See also description under the section 'Dissemination of knowledge and research results'.

UNEP Centre
The UNEP Collaborating Centre on Energy and the Environment, financed by the UN, Danida and Risø, provides technological-scientific support to the UN Environment Programme (UNEP), e.g. through energy and environmental projects in a number of developingcountries.

Strategic alliances, etc.

Risø collaborates strategically with closely-related scientific institutes to promote synergy, task sharing and the fulfilment of Risø's objectives. Risø thus has collaboration agreements with the National Environmental Research Institute (DMU), the Danish Technological Institute (DTI), The Royal Veterinary and Agricultural University (KVL), the Technical University of Denmark (DTU) and the Danish Academy of Technical Sciences.

Centre for Advanced Technology (CAT)
CAT is a science park established jointly by the Technical University of Denmark, the Roskilde University Centre and Risø. New high-tech companies can set themselves up here to carry out research and development in collaboration with researchers from the three institutions.

Engineering Science Centre
The centre has been established as a joint venture by the Danish Technical Scientific Research Council (STVF) and Risø. Research focuses on metallic materials, ceramics and polymers, as well as composite materials, with special reference to mechanical properties.

MP^{2}M
Risø participates in the MUP Centre for Materials Processes/Properties and Modelling in collaboration with the Technical University of Denmark and Aalborg University. The purpose is to strengthen interdisciplinary research in this area.

Danish Polymer Centre
The centre has been established as a joint venture by the Technical University of Denmark, a number of companies and Risø. Its purpose is to contribute to the competitive edge of the Danish plastics industry by means of a number of research and development projects.

Euratom-Risø Fusion Research Association
Risø participates in the EU fusion research programme through the Euratom-Risø association, and collaborates in particular with the Max Planck Institute of Plasma Physics in Garching on optical diagnostics and the numerical simulation of fusion plasmas.

Network collaboration

Risø participates in a number of networks:

DCAR The Danish Centre for Atmospheric Research.
DEG The Danish Environmental Group.
Enero The European Network of Environmental Research Organisations.
The EUREC Agency The European Renewable Energy Centers Agency.

Governing body

Professor Ulrik V. Lassen, M.D.
Novo Nordisk A/S
Chairman of the Board

Inge Thygesen, Senior advicer
Ministry of Finance
Vice Chairman of the Board

Adjunct Professor
Kurt Nørgaard Clausen, Ph.D.
Head of Programme
Risø National Laboratory
Elected by Risø's personnel

Søren Dalby, Deputy Director
Grundfos A/S

Erik Lindegaard, Director
Danish Environmental Protection Agency

Bjarne Weiler Madsen
Trade Union Representative
Danish Metalworkers' Union

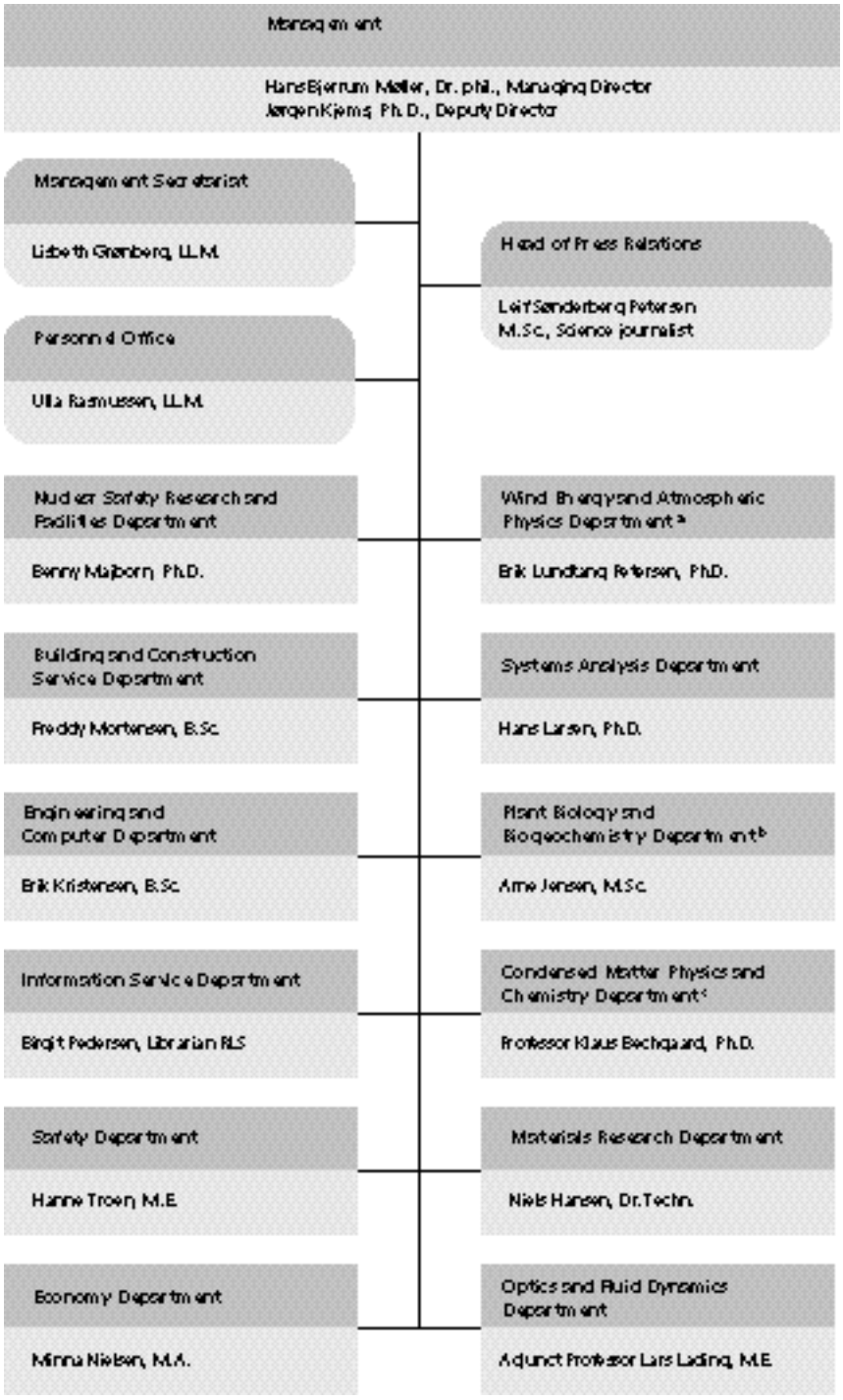
Professor Søren Molin
Laboratory of Microbiology
Technical University of Denmark

John Hebo Nielsen, Ph.D., Director
Gaia Technologies A/S

Jens Olsson, Research Technician
Risø National Laboratory
Elected by Risø personnel

Poul Skovgaard, Director

Lisbeth Grønberg, LL.M.
Risø National Laboratory
Secretary to the Board



a) Formerly the Department of Meteorology and Wind Energy
b) Formerly the Department of Environmental Science and Technology
c) Formerly the Department of Solid State Physics

Ph.D.-degrees in 1996

Steven Biegalski, B.Sc., University of Illinois (Nuclear Safety Research and Nuclear Facilities Department)
Jette Borg, M.E., DTU (Nuclear Safety Research and Nuclear Facilities Department)
Christian Bergenstof Nielsen, M.E., DTU (Materials Research Department)
Michael Stanley Pedersen, M.E., DTU (Materials Research Department)
Charlotte Bay Hasager, M.Sc., KU (Wind Energy and Atmospheric Physics Department)
Kristian Skriver Dahl, M.E., DTU (Wind Energy and Atmospheric Physics Department)
Carsten Dam-Hansen, M.E., DTU (Optics and Fluid Dynamics Department)
Michael Foged Lyngkjær, M.Sc., KU (Plant Biology and Biogeochemistry Department)
Henrik Chresten Pedersen, M.E., DTU (Optics and Fluid Dynamics Department)
Winnie E. Svendsen, M.Sc., KU (Optics and Fluid Dynamics Department)
Sønnik Clausen, M.E., KU (Optics and Fluid Dynamics Department)
Søren Weis Dahl, M.E., DTU (Plant Biology and Biogeochemistry Department)
John Myhre Frederiksen, M.Sc., KU (Plant Biology and Biogeochemistry Department)
Tamás Keszthelyi, M.Sc., KU (Plant Biology and Biogeochemistry Department)
Teis Nørgaard Mikkelsen, M.Sc., KU (Plant Biology and Biogeochemistry Department)
Peter Henrik Carstensen, M.Sc., RUC (Systems Analysis Department)

The following have received prizes, honorary titles, etc.

Kaj Heydorn, Dr.Techn., received the Eurolab Denmark Prize 1996.
Lars Lading, M.E., has been appointed adjunct professor at DTU for a five-year period commencing on 1 January 1996.
Peter Eskil Andersen, M.E., Ph.D., received the Danish Optical Society's DOPS award on 22 November 1996 for his work investigating so-called nonlinear cross-talk in photo-refractive materials.
Kurt Nørgaard Clausen, Ph.D., has been appointed adjunct professor at the University of Copenhagen.
Asker Aarkrog, M.E., Ph.D., has received the Professor N.V. Timofeeff-Ressovsky Memorial Medal from Russia.
Ole John Nielsen, Ph.D., has received the Henry Ford Technology Award in Detroit, USA.

Development in staff 1986–96.

	1986	1988	1990	1991	1992	1993	1994	1995	1996
Academic staff	*305*	*316*	*308*	*305*	*319*	*345*	*357*	*355*	*360*
Technical/administrative staff	*600*	*601*	*574*	*524*	*515*	*499*	*488*	*476*	*456*
Ph.D. and post docs	*24*	*33*	*41*	*37*	*55*	*65*	*73*	*96*	*104*
Students and trainees	*44*	*48*	*51*	*48*	*51*	*47*	*46*	*44*	*41*
Total staff (man years)	*973*	*998*	*974*	*914*	*940*	*957*	*964*	*971*	*961*

Man years have been revised in relation to earlier annual reports, due to a systematically inclusion of substitutes etc.

Education of scientists

In 1996, a total of 68 Ph.D.-students were associated with Risø. Of these, 48 had a grant jointly funded by the Research Academy and Risø, while 7 were financed by the Engineering Science Centre and 13 were financed in other ways. The agreement with the Research Academy on joint financing of scientist education grants to Ph.D.-candidates was renewed in 1996 for a further three-year period commencing 1 January 1997. The number of post doctoral grant recipients has increased from 41 in 1995 to 51 in 1996, including 17 from abroad. The collaboration that began in 1994 with the post-doctoral committee under ATV on the establishment of a pilot experiment with post-doctoral projects, led in 1996 to the establishment of a further 2 post doctoral courses, making a total of 8 courses in collaboration with private Danish companies.

Jarl Bregninge
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Center for Advanced Technology (CAT)

CAT is the result of collaboration between Risø National Laboratory, the Technical University of Denmark and the Roskilde University Centre (RUC) for the purpose of increasing collaboration between industry and research. CAT puts premises at the disposal of knowledge-based firms situated in the immediate vicinity of the three parent institutions. Located in the science park, firms can work together with researchers from the institutions on joint development projects, or firms can draw on the expertise of the institutes in other ways. In CAT, researchers who see commercial possibilities for their research can test out their ideas in a commercial environment, while retaining specialist contact with the world of research. Together with the staff of the institutions, CAT undertakes to identify and solidify the commercial development assignments based on research carried out at the mother institutions. The CAT building at Risø is fully let and now houses 22 firms and projects. In 1997 Roskilde County joins the CAT foundation and CAT will be taking over the Niels Bohr Institute buildings at Risø. In the autumn, CAT will be moving into a new building at RUC, and at the end of 1997, into new premises at the Micro-electronics Centre at the Technical University of Denmark. Altogether, CAT will then have more than approximately 8,500 m^2 of office and laboratory space available. Further information on CAT and companies at CAT can be obtained via Internet at URL http://www.catscience.dk.

Flemming Bahner
cat@catscience.dk

Information

Information about Risø and Risø's research is made available on Internet through Risø's World Wide Web service. Risø's research is also communicated through research profiles and bibliographical information on employee publications by Risø's staff in the national DANDOK research database as well as in international information systems. Risø's external publication, RisøNyt, is issued four times a year and covers current research topics at Risø. In October, the Risø Visitor Centre was officially inaugurated by the former Minister of Research Frank Jensen. The purpose of the Visitor Centre is to give visitors an up-to-date overview of research at Risø. This is done by means of audio-visual presentations, lectures, demonstration experiments and interactive exhibitions. Finally, 8th to 10th grade school classes can work on experiments related to Risø's research at the Visitor Centre's school laboratory. In 1996, more than 4,500 visitors were received, representing almost 200 groups of visitors.

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Risø Library

The library is open to the public and is used by individuals, businesses, government authorities, institutions and other libraries. In addition to its printed collections, including approximately 1,300 current scientific journals, the library has a large number of electronic information products available.

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Patent applications in 1996

Bates, F.S.; Rosedale, J.H.; Schulz, M.F.; Almdal, K., Miscible polyolefin blends with modifying polyolefin having matching segment lengths. US Patent 5,571,864 A (5 Nov 1996).

Berg, R.H.; Hvilsted, S.; Ramanujam, P.S., Novel organic cpds. for use in holographic cinematography – having physical functionality which can be influenced by external stimulation, used for optical storage of information. WO Patent 96/38410 (5 Dec 1996).

Glückstad, J., Phase contrast imaging. WO Patent 96/34307 (31 Oct 1996).

Hvilsted, S.; Ramanujam, P.S.; Andruzzi, F., Optical storage medium. US Patent 5,496,670 A (5 Mar 1996).

Risø's publications in international journals

Risø emphasises making its research results accessible through publication in international refereed journals. Refereed means that an evaluation panel of internationally recognised researchers reads through and criticises each article several times before it is approved for publication. An increase in the number of articles published in internationally recognised journals is thus a primary indicator as to whether Risø is developing in the desired direction.

The American Institute for Scientific Information (ISI) is the institute most often used in the preparation of publications analyses, and Risø has, therefore, decided to use data from ISI to account for its articles in refereed journals. The ISI indexes more than 4,000 international journals in the natural science and technology field and 3,000 journals in the field of social science and humanities (ISI's 'source journals'). It is thus assumed that by far the majority of internationally recognised journals are included in the ISI system. The ISI's article analyses cover 'general' scientific articles, reviews, proceedings papers and notes, as well as letters, book reviews, discussions, meeting abstracts, etc.

The ISI has given Risø an 'Institutional Citation Report' in the form of an electronic database formed by searching for 'Riso' or 'Risoe', so that the database includes all the articles where Risø is listed as an author address. On the basis of the database, it can be determined how many articles Risø has published in ISI's source journals. The result can be seen in *Figure 1:*

In order to compensate for the random variation from year to year, the publications in *Figure 1* are listed with five-year overlapping windows showing the number of articles published within the five-year period. From the figure, it can be seen that publishing activity has doubled over the last ten years.

From the ISI database, it is also possible to count how many times the articles have been cited. This gives a further measure of how visible Risø's research is in the international research world. *Figure 2* below shows the total number of citations in the same period breakdown as in *Figure 1*. The figure shows how many citations have been made, for example in the period 1981–85, of articles published in the same period. This means, for example, that citations made in 1988 are not included in the accounting for the period 1981–85. This gives a better basis for comparison of the frequency of citations in different periods. If the citations had been accounted as of today's date, it would have been difficult to compare 1981–85 with 1991–95, for example, because articles from 1991–95 have not been available as sources for citations for as long a time as articles from 1981-85. *Figure 2* shows that Risø's visibility in the international world of research is growing. If *Figure 1* is compared with *Figure 2,* an average can be calculated for how much a Risø article is cited in the same time span as the publications. In recent years, Risø has achieved on average between four and five citations per article during the same time span as the publications, whereas the number was formerly just over three.

The ISI database also shows how much a particular article 'should' be cited. The ISI determines how often an article published in a particular journal ought to be cited. This is done by calculating the average number of citations of articles of the same type and in the same journal over a number of years. In this way, a target can be set for how often an article can be expected to be cited. This provides a basis for determining whether one's own articles come above or below the average. According to the ISI's computations, in the last 10 years, with the exception of 1990, Risø has been cited more than would be expected. Measured in relation to citations of other international articles, Risø's articles are cited on average more than would be expected.

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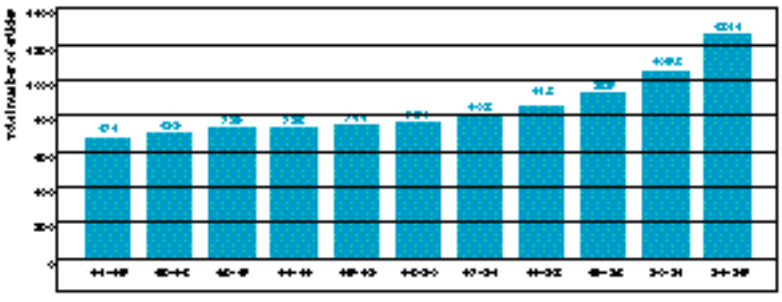


Figure 1: Number of articles published in internationally recognised journals (ISI Source Journals) listed within five-year overlapping windows.

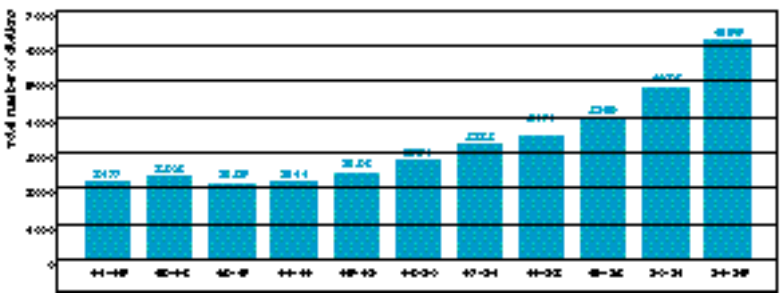
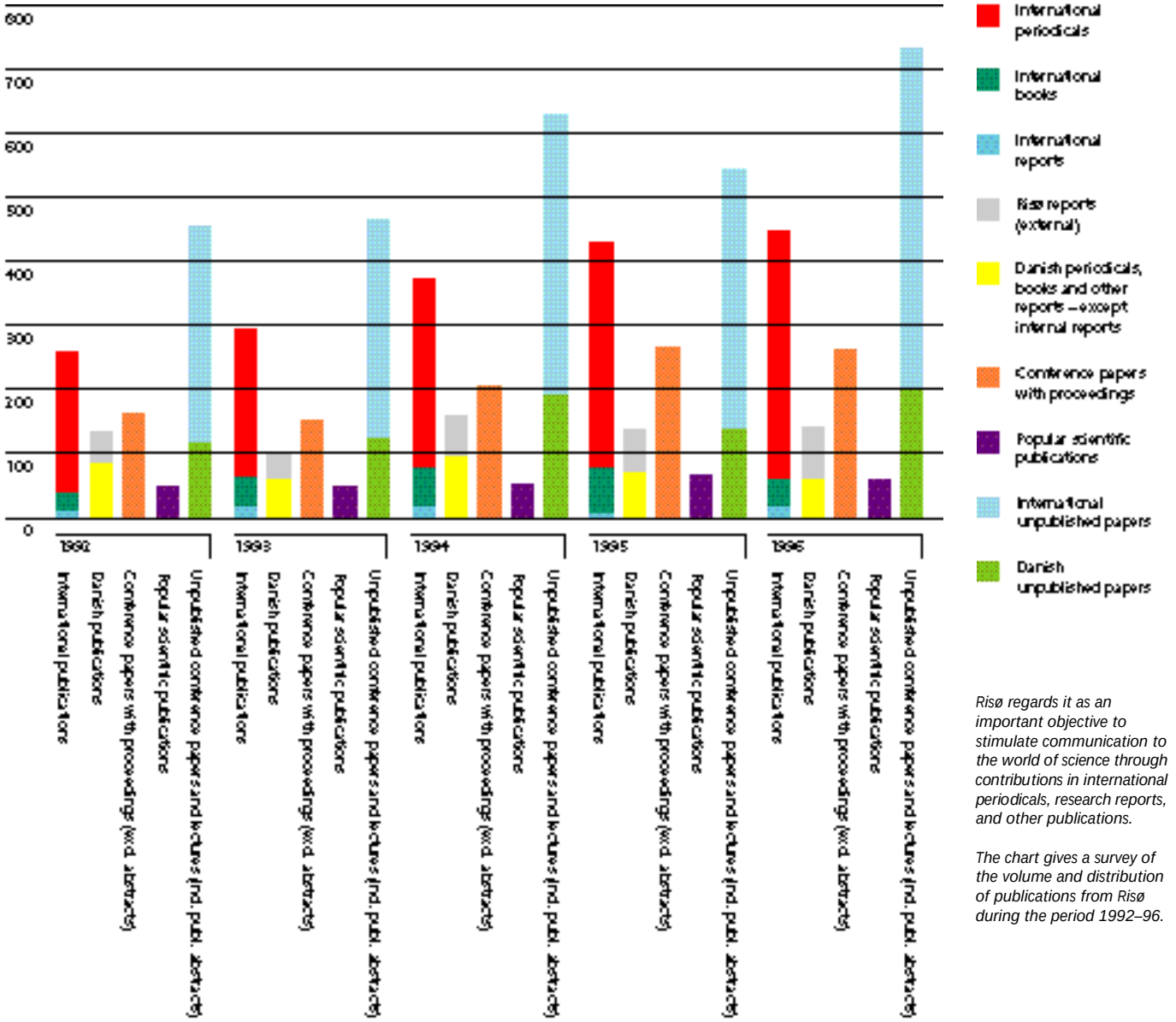


Figure 2: Number of citations of Risø's articles published in internationally recognised journals within the same 5-year period in which the articles were published.

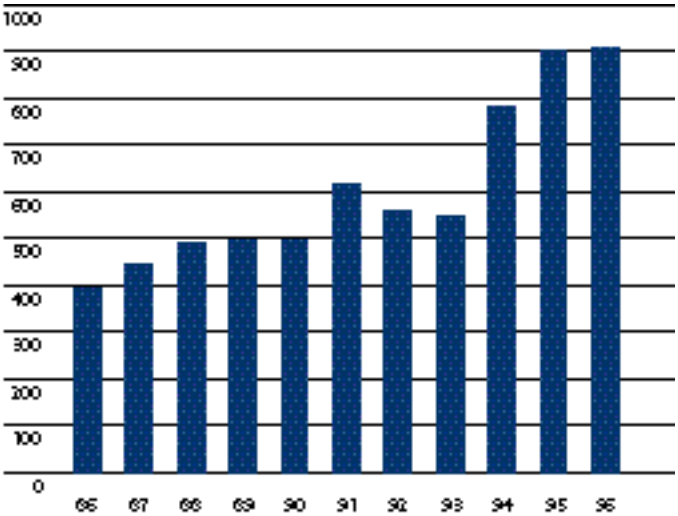
Communication of results 1992–96



Risø regards it as an important objective to stimulate communication to the world of science through contributions in international periodicals, research reports, and other publications.

The chart gives a survey of the volume and distribution of publications from Risø during the period 1992–96.

Publications (totals) 1986–96



The chart shows the totals of Risø's publication activities. The totals comprises the first four columns of each year from the preceding chart. During the period 1986–91 the figures include published abstracts.

The list on the following pages comprises references to all scientific publications from Risø published in 1996.

Industrial materials

Aaberg, R.J.; Tunold, R.; Poulsen, F.W.; Bonanos, N., Short term structural changes in NiO/YSZ electrodes upon reduction. In: Second European solid oxide fuel cell forum. Proceedings. Vol. 1. 2. European solid oxide fuel cell forum, Oslo (NO), 6-10 May 1996. Thorstensen, B. (ed.), (European SOFC Forum, Oberrohrdorf (CH), 1996) p. 363-372

Ahlgren, E.O., Thermoelectric effects in an SOFC. In: Second European solid oxide fuel cell forum. Proceedings. Vol. 1. 2. European solid oxide fuel cell forum, Oslo (NO), 6-10 May 1996. Thorstensen, B. (ed.), (European SOFC Forum, Oberrohrdorf (CH), 1996) p. 463-472

Ahlgren, E.O.; Hansen, J.R.; Bonanos, N.; Poulsen, F.W.; Mogensen, M., Electrical characterisation of $SrCe_{0.95}Y_{0.05}O_{3-\delta}$. In: High temperature electrochemistry: Ceramics and metals. Proceedings. 17. Risø international symposium on materials science, Risø (DK), 2-6 Sep 1996. Poulsen, F.W.; Bonanos, N.; Linderoth, S.; Mogensen, M.; Zachau-Christiansen, B. (eds.), (Risø National Laboratory, Roskilde, 1996) p. 161-166

Ahlgren, E.O.; Poulsen, F.W., Thermoelectric power of doped cerium oxide. *J. Phys. Chem. Solids* (1996) v. 57 p. 589-599

Ahlgren, E.O.; Poulsen, F.W., Thermoelectric power and electrical conductivity of strontium-doped lanthanum manganite. *Solid State Ionics* (1996) v. 86/88 p. 1173-1178

Akdut, N.; Foct, J., Microstructure and deformation behavior of high nitrogen duplex stainless steels. *ISIJ Int.* (1996) v. 36 p. 883-892

Akdut, N.; Foct, J.; Gottstein, G., Cold rolling texture development of alpha/gamma duplex stainless steels. *Steel Res.* (1996) v. 67 (no.10) p. 450-455

Albertini, G.; Cernuschi, F.M.; Cicognani, G.; Ghia, S.; Lorentzen, T.; Rustichelli, F., Residual strain measurements in welded steel Fe510D. *Appl. Radiat. Isot.* (1995) v. 46 p. 731-732

Alcock, J.; Toft Sørensen, O.; Jensen, S.; Kjeldsteen, P., Comparative wear mapping techniques I: Friction and wear mapping of tungsten carbide/silicon carbide. *Wear* (1996) v. 194 p. 219-227

Alcock, J.R.; Sørensen, O.T., Slurry abrasion resistance of engineering ceramics. *Brit. Ceram. Trans.* (1996) v. 95 p. 30-34

Andersen, B.S.; Sørensen, N.J., Analysis of crystalline solids by means of a parallel FEM method. In: Applied parallel computing: Computations in physics, chemistry and engineering science. PARA'95. 2. International workshop, Lyngby (DK), 21-25 Aug 1995. Dongarra, J.; Madsen, K.; Wasniewski, J. (eds.), (Springer-Verlag, Berlin, 1996) (Lecture notes in computer science, 1041) p. 17-23

Andersen, S.I.; Brøndsted, P.; Lilholt, H., Fatigue of polymeric composites for wingblades and the establishment of stiffness-controlled fatigue diagrams. In: 1996 European Union wind energy conference. Proceedings. EWEC '96, Göteborg (SE), 20-24 May 1996. Zervos, A.; Ehmann, H.; Helm, P. (eds.), (H.S. Stephens & Associates, Bedford, 1996) p. 950-953

Andersen, S.I.; Brøndsted, P.; Jørgensen, O.; Lilholt, H., Damping properties of polymers and polymeric composites for wingblades. In: 1996 European Union wind energy conference. Proceedings. EWEC '96, Göteborg (SE), 20-24 May 1996. Zervos, A.; Ehmann, H.; Helm, P. (eds.), (H.S. Stephens & Associates, Bedford, 1996) p. 954-959

Andersen, S.I.; Brøndsted, P.; Lilholt, H.; Lystrup, Å., Risø investigations of GI-UP materials. In: Kensche, C.W. (ed.), Fatigue of materials and components for wind turbine rotor blades. EUR-16684 (1996) p. 71-119

Andersen, S.I.; Lilholt, H.; Lystrup, Å., Properties of composites with long fibres. In: Design of composite structures against fatigue. Applications to wind turbine blades. Mayer, R.M. (ed.), (Mechanical Engineering Publications Ltd., Bury St. Edmunds, 1996) (EUR-16687) p. 15-31

Appel, C.C., Zirconia stabilized by Y and Mn: A microstructural characterization. *Ionics* (1995) v. 1 p. 406-413

Appel, C.C.; Horsewell, A.; Bilde-Sørensen, J.B., Applications in materials science of the environmental scanning electron microscopy (Session T6). In: 11. European congress on electron microscopy. EUREM '96, Dublin (IE), 26-30 Aug 1996. (International Federation of Societies for Electron Microscopy, Dublin, 1996) 1 CD-ROM

Armstrong, W.D., A one-dimensional model of a shape memory alloy fiber reinforced aluminum metal matrix composite. *J. Intell. Mater. Syst. Struct.* (1996) v. 7 p. 448-454

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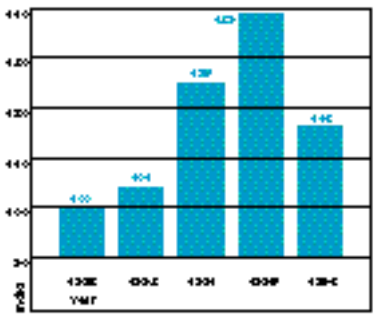
Environmental statistics for Risø National Laboratory

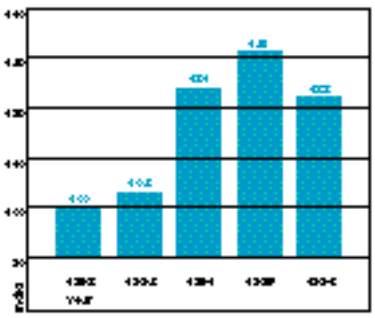
	Environment score 1995	Environment score 1996	Risø 1996	Threshold or typical value[a]
Injunctions, etc.				
Injunctions from the environmental authorities (number)	0	0		
Petitions from environmental authorities (number)	2	0		
Injunctions from the Labour Inspection Service (number)	2	4		
Guidance from the Labour Inspection Service (number)	2	1		
Instances of exceeding threshold values for sewage (number)	2	1		
Violation of 'Conditions for operating nuclear facilities' (number)	0	7		
Special reports on the nuclear facilities (number)	3	0		
Risks				
Accidents reported (number)	24	23		
Injuries treated in Risø's emergency room (number)	137	111		
Injuries reported to the Labour Inspection Service (number)	10	9	9 per 1.000[b]	6 per 1.000[c]
Injuries reported to the Occupational Injuries Agency (number)	1	3		
Maximum individual effective dose[d] (mSv)	13.0	9.1	9.1 mSv	20 mSv[e]
Overall annual effective dose[f] (mSv per person)	260.9	253.0		
Consumption				
Water consumption (m^3)	68,500	80,720	84 m^3/PE	62 m^3/PE[g]
Power usage (MWh)	15,000	14,150	127 kWh/m^2	38 kWh/m^2[h]
Heating (MWh)	15,540	17,244	192 kWh/m^2	60 kWh/m^2[i]
Natural gas (m^3)	1,416,405	1,823,885		
Coolants[j] (kg)	366	281		

In 1996, the Board of Management decided, based on preliminary studies, to introduce environmental management from 1 January 1997. For 1996, Risø has produced its first Environmental Status Report.

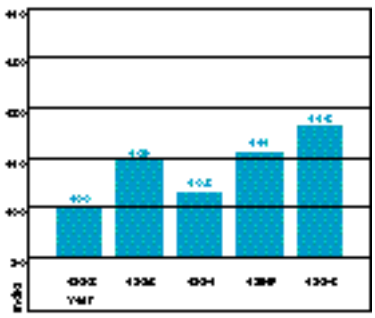
The Risø Environmental Status Report contains information on the consumption of raw materials in the form of water, power, heating, natural gas and coolants, as well as discharges affecting the surroundings in the form of atmospheric emissions, sewage, sludge and other waste. Also included are effects on staff in the form of risks, covering accidents at work and radiation doses. The Environmental Status Report also contains an account of Risø's capacity to abide by legislation in terms of injunctions, etc.



Environmental activity index of water consumption 1992–96.



Environmental activity index of heating 1992–96. (Adjusted heat use excluding heat loss through pipelines)



Environmental activity index of power usage 1992–96. (Total power consumption).

Environmental activity index (ØAI):

The environmental activity is indicative of how well Risø uses resources. 1992 is used as the basis year.

An increase in the index is interpreted as better use of the resource.

	Environmental score 1995	Environmental score 1996	Risø 1996	Threshold or typical value[a]
Atmospheric emissions				
Argon (GBq)	38,000	23,000		
Tritium (GBq)	5,300	21,000	0.9 µSv/year[k]	200 µSv/year[l]
Iodine (GBq)	0.0099	0.0077		
Radioactive carbon dioxide (^{14}C-emissions)				
from bitumen facility (GBq)	6	8		
Particular ß activity from distillation facility (GBq)	0.00031	0.00036		
Sewage, etc.				
Sewage (m^3)	65,600	61,400	61,400 m^3	255,500 m^3
COD[m] (kg)	4,815	3,438	56 mg/l	200 mg/l[n]
Bl_5[o] (kg)	1,312	878	14 mg/l	40 mg/l[n]
Suspended particles (kg)	1,758	890	15 mg/l	60 mg/l[n]
Total nitrogen (kg)	1,463	1,019	17 mg/l	40 mg/l[n]
Total phosphorus (kg)	269	190	3.1 mg/l	10 mg/l[n]
Heavy metals[p] (kg)	2.6	*[q]		
of which zinc (kg)	1.7	*[q]	26 µm/l[r]	1.000 µm/l
Unspecified ß activity in treated sewages[s] (GBq)	0.077	0.100	0.00160 Bq/ml	0,15 Bq/ml
Tritium with distilled active sewage (GBq)	3000	3700		
Tritium in secondary cooling water from DR3 (GBq)	50	480	3.0 kBq/ml	370 kBq/ml
Sewage sludge				
Quantity of sludge (tons)	5	5		
Heavy metals[t] (g)	14,400	*[q]		
of which Mercury (g)	12	*[q]	2.4 mg/kg[u]	0.8 mg/kg[v]
Cadmium (g)	75	*[q]	15 mg/kg[u]	0.8 mg/kg[v]
Nickel (g)	270	*[q]	54 mg/kg[u]	30 mg/kg[v]
Lead (g)	540	*[q]	108 mg/kg[u]	120 mg/kg[v]
Copper (g)	3,300	*[q]	660 mg/kg[u]	1,000 mg/kg[v]
Zink (g)	9,540	*[q]	1,908 mg/kg[u]	4,000 mg/kg[v]
Waste				
Waste to be disposed of outside Risø (tons)	162	182		
of which chemical waste[w] (tons)	10.9	3.9		
Waste for recycling (tons)	27	28		
Waste for disposal	19	18		
of which low-activity waste[x] (tons)	11	9		

Table 1: Effective doses, 1992–96. Dosemeters with non-recorded doses are not included. The dose limit is 50 mSv per year for any given year and 100 mSv over a five-year period. It can be seen that for each year, more than 80% of doses are lower than 10% of the dose limit. No significant trend can be seen from year to year.

	1992	1993	1994	1995	1996
Dose interval in mSv	Number	Number	Number	Number	Number
0.00 – 0.19	45	60	83	71	66
0.20 – 0.50	91	89	97	70	60
0.51 – 1.00	38	42	42	34	31
1.01 – 2.00	32	45	35	34	28
2.01 – 3.00	16	22	19	17	15
3.01 – 4.00	11	12	7	4	17
4.01 – 5.00	5	2	5	4	4
5.01 – 6.00	5	8	4	6	2
6.01 – 7.00	1	1	1	1	1
7.01 – 8.00	4	2	1		2
8.01 – 9.00	2		3	4	2
9.01 – 10.00		2	2	1	1
10.01 – 11.00		1			
11.01 – 12.00		1		1	
Total number of occupational exposed workers:	**250**	**287**	**299**	**247**	**229**

The figures for 1995 and 1996 are given in order to show Risø's development. Limits or typical reference values are given to enable an assessment of Risø's adverse impact in relation to these.

Risø has complied with all injunctions, etc., from government authorities. Risø regards violations as a serious matter and has taken the initiative to reduce their incidence in future.

An environmental activity index (ØAI) has been set up for the areas of consumption of water, power and heat. Over the period 1992–96, there was an improvement in all areas, although a slight setback was observed in the ØAI for water and heat consumption in 1996. It emerges from the figures that Risø's consumption in all three areas is rather high in relation to the control values. This is because Risø has a greater number of large experimental facilities than do the universities, for example the DR 3 reactor.

As an institution, Risø is unique in Denmark because it operates nuclear facilities. As the environmental status report shows, adverse impact from this lies below 'accepted' values.

Risø's sludge contains higher concentrations of heavy metals than is permitted for sludge destined for use on agricultural land. Risø's sludge is not used for this purpose – it is disposed of at controlled disposal facilities.

In 1996, Risø changed its purchasing policy to include environmentally friendly purchases, as well as to prepare an action plan describing how Risø intends to take environmental and energy factors into account in its purchasing, cf. the Danish Environmental Agency's circular no. 26 of 7 February 1996. The 1996 action plan for environmentally friendly purchases includes paper, printed matter, data processing and research apparatus, and is included in the plan for 1997. All objectives formulated in the 1996 action plan were met.

Units and abbreviations for activity and radiation doses:
Activity: Becquerel, Bq: 1 Bq = 1 disintegration/second
Radiation dose: Sievert, Sv: 1 Sv = 1 joule/kg

[a] In cases where Risø's endorsements contain threshold values, these are noted. In some fields there are no threshold values. In some cases values have been found that are characteristic of similar areas/fields to allow comparison of Risø's consumption, etc.

[b] Per 1000 man years.

[c] Per 1000 employees in research institutes. For teaching and research as a whole: 9 accidents per 1000 employees. Source: AT-Arbejdsskaderegisteret BSR (Occupational Injuries Register). Reported industrial accidents 1984–88. Labour Inspectorate 1990.

[d] Maximum individual effective dose: the individual effective dose is defined as the sum of the equivalent doses to the individual organs multiplied by their respective tissue weight factors for the individual employee. The maximum individual effective dose corresponds to the maximum dose an individual employee has received.

[e] Radiation protection: in the area of radiation protection, dose-limitation principles are applied. These state that doses from exposure to radiation at work should be kept as low as reasonably achievable and that doses must not exceed the dose limits set by the governmental authorities. Effective dose: 5-year periods: 100 mSv/5 years = 20 mSv/year average. Individual year: maximum 50 mSv/year.

[f] The collective dose of Risø employees is defined as the sum of the individual doses received by all persons (effective doses).

[g] Roskilde municipal sewage plan, 1988.

[h] For universities (DEFU). Electric power consumption at Risø cannot be precisely compared with this, as activities such as operation of DR3 and the accelerator require very high power consumption.

[i] For universities (DEFU). For administrative buildings, consumption has been set at 170 kWh/m^2 (Energy Management Agency).

[j] Coolants: account of consumption of fully and partially halogenised hydrocarbons used for cooling purposes. A small portion of this is used for research purposes.

[k] Doses of tritium, argon and iodine are summary doses at the perimeter fence.

[l] The maximum contribution from each source is suggested by various Danish government authorities as between 100 and 300 µSv/year. Emissions at Risø are thus far below suggested levels.

[m] COD is the chemical oxygen consumption.

[n] The values given are identical to those applicable in 1995. During 1996, however, several of the values have been amended to take account of new discharge allowances.

[o] BI_5 is the biochemical oxygen consumption measured over 5 days.

[p] The total content of the heavy metals which Risø analyses in sewage.

[q] * indicates that the figure for 1996 was not available by the deadline.

[r] Calculated on the basis of figures from 1995.

[s] Unspecified ß activity: total activity non specified.

[t] Total heavy metal content analysed by Risø in sludge.

[u] Calculated based on figures from 1995.

[v] Threshold for heavy metal content in sludge is applicable if the sludge is applied to land to be used for agricultural purposes. Risø's sludge is not currently used for this purpose, but is disposed of at controlled disposal facilities.

[w] In recent years, chemical stocks at Risø have been cleared out. This explains the quantity of chemicals sent to the municipal disposal facility for chemicals is still higher than normal.

[x] Low-activity waste: in addition to the low-activity waste resulting from Risø's own activities, Risø receives low-activity waste from all over Denmark in the form of small quantities of radioactive isotopes. Low-activity waste is defined as radioactive waste for which the dose rate at a distance of 1 m from the centre of the waste container does not exceed 100 µSv/h.

Operating statement for the state institution Risø

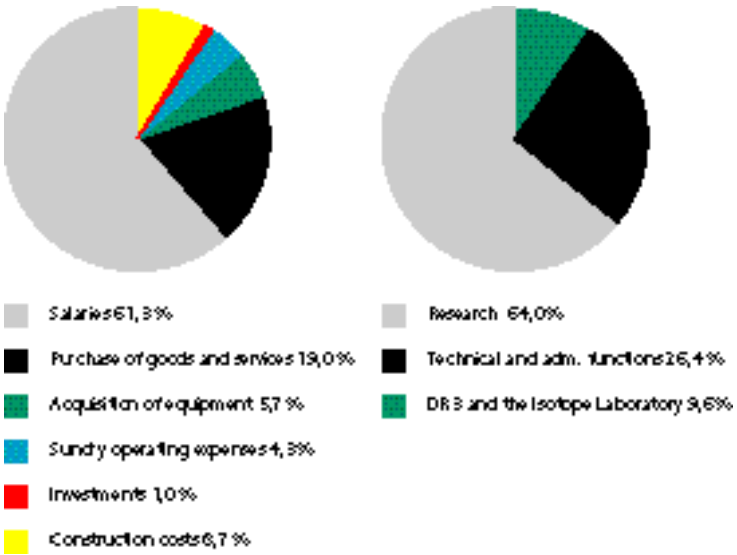
DKK million at current prices (excluding VAT)	Accounts 1995	Accounts 1996	Budget 1997 *	Notes
Government appropriations to operating, plant and equipment costs (corrected net figures)	245,7	253,0	259,9	
Contract earnings	202,5	207,4	223,2	
Total income	**448,2**	**460,4**	**483,1**	
Wages and salaries	268,3	280,0	289,5	
Other operating costs:	191,0	152,1	169,7	1
– Purchases of goods and services	106,5	90,8		
– Acquisition of equipment	55,1	30,4		
– Leases, rentals, maintenance and taxes	17,2	15,4		
– Sundry operating costs	2,7	5,5		
– Grant for education of scientists	9,5	10,0		
Construction and building	63,2	41,2	25,8	1
Total expenses	**522,6**	**473,3**	**485,0**	
Result (to be carried forward)	**(74,4)**	**(12,9)**	**(1,9)**	
Halden project (statutory)				
Government appropriation	1,6	1,6	1,6	
Grant	1,5	1,5	1,6	
Result (cannot be carried forward)	0,1	0,1	–	

Note 1: Investments

DKK million at current prices	Accounts 1995	Accounts 1996	Budget 1997*
Investments in research equipment	46,7	4,6	5,3
Construction and building	63,2	41,2	25,8
Total	**109,9**	**45,8**	**31,1**

*as of March 1997

Percentage distribution of expenses 1996



Distribution of expenses 1996 by areas

Balance sheet at the end of December

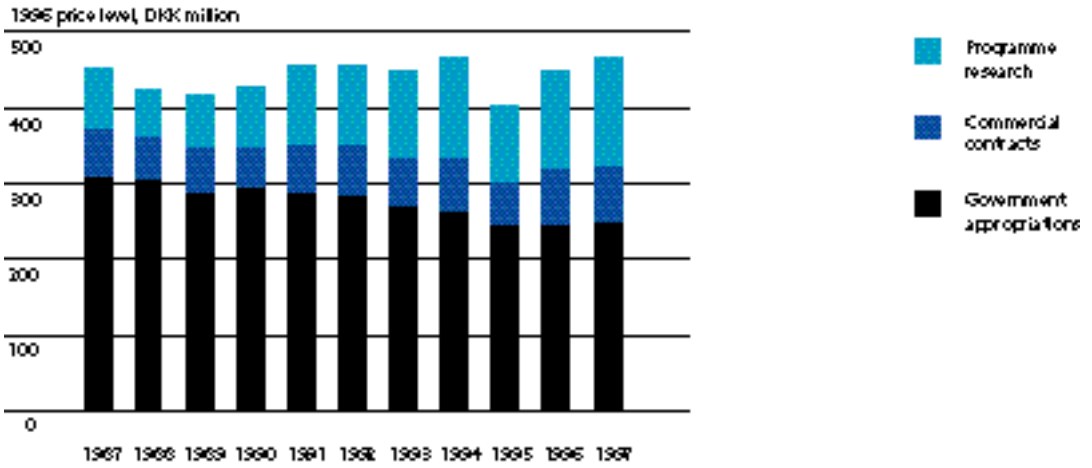
DKK million at current prices	Accounts 1995		Accounts 1996		Notes
Assets					
Tangible fixed assets	**190,6**		**222,4**		1
Current assets					
Accounts receivable:					
– Receivables from sales and services		79,6		88,3	2
– Outlays relating to partners, etc.		3,5		3,8	3
– Other receivables		5,1		0,0	
– Securities	88,4	0,2	92,4	0,2	
Liquid holdings	0,7		1,2		
Total current assets	**279,6**		**93,5**		
Total assets			**315,9**		
Liabilities					
State financing of Risø's activities					4
State financing of plant and equipment	190,6		222,4		
State financing of other assets	31,2		67,9		5
Accumulated result from operations:					6
– Reserved for special purposes		47,5		20,0	
– Available	44,8	(2,7)	1,9	(18,1)	
Total state financing of Risø's activities	**266,5**		**292,1**		
Other financing (short-term debt)					
Prepayments		3,4		1,6	7
Contributions from EU to partners		3,2		22,1	8
Trade creditors for goods and services, including payable VAT	**13,1**	6,5	**23,8**	0,1	
Total debt	**13,1**		**23,8**		
Total liabilities	**279,6**		**315,9**		

Specification of accumulated profits

Accumulated profits (DKK million):	1995	1996	Budget 1997	Notes
Accumulated at the beginning of the year	119,4	44,8	1,9	6
Year's profit	(74,4)	(12,9)	(1,9)	
Finance Ministry's adjustment of net wealth		(30,0)	–	
Accumulated at the end of the year	**45,0**	**1,9**	**–**	
Of which reserved for specific purposes				
– Reprocessing of reactor fuel*	6,5	9,0	–	
– Purchase of CAT building*	11,0	11,0	–	
– Unforeseen drop in contract activities	30,0	0	–	
Total reservations for special purposes	**47,5**	**20,0**	**–**	
Disposable reserves	**(2,5)**	**(18,1)**	**0,0**	

*The reservations are included in the operating budget for 1997.

Income development



Generally

The balance sheet and the following notes are prepared according to the principles determined in co-operation with the Auditor-General of Denmark (Rigsrevisionen) in 1995.

Notes

1 The book value of fixed assets at the end of 1996. The amount is an accumulation of acquisitions through the years reduced by the value of depreciation. 5% of the accumulated balance is depreciated using the straight-line method according to the Budget Guidelines. In comparison, Risø's property was valued at DKK 326 million in the official property valuation in 1996. Machines, fixtures and fittings are usually not included in fixed assets' book values.

2

Receivables from sales and services (DKK million):	1995	1996
Costs met that are invoiced in the following financial year: (EU projects, etc.)	15,2	19,1
Accounts receivable:	64,4	69,2
Total receivables from sales and services:	79,6	88,3

3 Advances and prepayments relating to different partners and subscribers.

4 Can be compared to equity capital in a private company. For a state institution, this is part of the liabilities that cannot be attributed to external capital equal to state financing of the institution's activities.

5 Inter-institutional account with the Agency of Financial Management & Administrative Affairs for financing of other current assets. Note that the accumulated result of the operations is included herein among Risø's receivables.

(DKK million):	1995	1996
Accumulated result of operations (see also note 6)	(44,8)	(1,9)
Financing of securities	0,2	0,2
Inter-institutional account with the Agency of Financial Management & Administrative Affairs	75,8	69,6
State financing of others assets:	31,2	67,9

6 In line with fluctuation scheme for state businesses. The balance is within the allowable range. Risø's accumulated profit was adjusted for grant to long-term unemployed from DKK 45 million in the annual accounts for 1995 to DKK 44.8 million after a correction of the net total during the audit.

7

Prepayments (DKK million):	1995	1996
Prepayments from EU	1,6	0,1
Other prepayments for later payment	1,8	1,5
Total prepayments:	3,4	1,6

8 The amounts relate to EU projects for which Risø must later settle with partners.

This list contains acronyms and abbreviations other than those explained in the text.

AAU Århus University.
AGR Advanced Gascooled Reactor.
AUC Aalborg University.
BRITE An EU programme, Basic Research in Industrial Technology for Europe.
CAT Centre for Advanced Technology. Science park established jointly by Risø, RUC and DTU.
CO_2 Carbon dioxide. A gas produced by burning fossil fuels. CO_2 belongs to the group of gases contributing to the greenhouse effect.
DEFU Research Institute for Danish Electrical Utilities.
DMI Danish Meteorological Institute.
DMU National Environmental Research Institute.
DTI Danish Technological Institute.
DTU The Technical University of Denmark.
EFP The energy research programme of the Danish Ministry of Environment and Energy.
ELKRAFT An electrical utility group on the Danish island of Zealand.
ELSAM An electrical utility group for the Danish mainland, Jutland, and the island of Funen.
EUCLID European Cooperation for the Long Term in Defence. An EU research programme.
EURAM An EU programme. European Research in Advanced Materials.
EUREKA European Research Coordination Agency.
FØTEK2 The Danish food technology research and development programme.
IAEA International Atomic Energy Agency.
IPCC Inter-government Panel on Climate Change.
JOULE Joint Opportunities for Unconventional or Long-term Energy Supply, the EU energy programme on non-nuclear energy and efficient exploitation of energy.
KVL The Royal Veterinary and Agricultural University.
KU The University of Copenhagen.
MATE Multi-Aircraft Training Environment.
MUP The Danish Materials Technology Programme.
MW Megawatt. 1 million watts.
NAA Neutron activation analysis. Analysis technique in which neutron irradiation of a material activates atoms, which can then be identified and counted.
Neutron scattering Analysis technique based on the scattering of neutron beams by atoms.
NKS Nordisk kernesikkerhedsforskning – Nordic Nuclear Safety Research. A Nordic committee with participants from government authorities, research institutes and companies involved in nuclear power.
NKT NKT – a Danish company.
RUC Roskilde University Centre.
SANS Small Angle Neutron Scattering. Equipment for studying, e.g. radiation damage in metals, polymers and bio-technological materials. With special low-energy neutrons, the equipment allows the study of materials with larger atomic distances.
SIS The Danish Institute of Radiation Hygiene.
SNF The Danish Natural Science Research Council.
SMP The Danish Strategic Environmental Research Programme.
SOFC Solid Oxide Fuel Cell. Fuel cells made of ceramic materials.
UNEP United Nations Environment Programme.
WAsP Wind Atlas Analysis and Application Program, developed at Risø.

Editor	Leif Sønderberg Petersen
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Translation	Interpen Translation A/S
Photos	Boye Koch, unless otherwise stated
Design	Per Mollerup Designlab A/S
Reproduction and printing	Center Tryk
Paper	Consort Royal Osprey Silk Tin 50% recycled paper 100% free of clorine
Illustration on front cover	The figure shows a 'snap-sho from a dynamic simulation of polyethylene on a quartz surface. One polymer chain is highlighted in order to demonstrate how one part o the chain is interacting with the quartz surface. The mode was created by using softwar from Molecular Simulations In (Discover® og Insight II®).

Risø Annual Report 1996
April 1997

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This annual report and other information
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ISBN 87-550-2296-0
ISSN 0908-729X